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RESEARCH BULLETIN NO. 16

THE UNIVERSITY OF NEBRASKA

BULLETIN

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AGRICULTURAL EXPERIMENT STATION

OF

NEBRASKA

FREEZING INJURY OF SEED CORN

T. A. KIESSELBACH AND J. A. RATCLIFF

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SUMMARY

1. Injury to seed corn by freezing in the fall is of frequent occurrence in Nebraska. The underlying causes of such injury are: (1) Late maturity, (2) abnormally early freezing weather.

2. The embryo, which is the vital part of a corn kernel, is in reality a rudimentary corn plant, having small leaves, stalk, and root.

3. In the normal process of germination, or growth of the embryo, the primary root develops more rapidly than the plumule.

4. The embryo and endosperm of a kernel of corn develop approximately at the same rate from the time of fertilization until maturity, and the power of germination is attained in about 20 days after fertilization.

5. The embryo and endosperm in an air-dry kernel of corn contain practically the same percentage of moisture. However, during the period just before maturity the percentage is greater for the embryo.

6. When immature or moist kernels of corn are sufficiently exposed to freezing temperatures, ice is formed in the intercellular spaces and in the larger spaces around the scutellum, plumule, primary root, and root sheath.

7. Severe freezing of immature or moist corn causes the embryo to change from a normally light or creamy color to a dark or yellowish brown color. This change is usually accompanied by a loss of vitality. The appearance of the embryo, therefore, is a fairly safe guide in judging the germinative power of seed corn which has been subject to freezing injury.

8. So far as could be detected from microscopic examinations of frozen embryonic tissues, there was no rupturing of cell walls or other cytological effect of freezing and ice formation. The change in color of the embryo as a result of freezing would seem to indicate that a chemical change had taken place.

9. The real cause of death from freezing of plant tissues is a difficult matter to determine. Nevertheless, several theories based on certain observations have been advanced to explain it. The most generally accepted theory is that water is withdrawn from the cells during the process of freezing, and that this process continues until death results from desiccation of the protoplasm. The most satisfactory explanation, however, in the light of the evidence at hand, is found in the theory, that freezing produces a physical or chemical change, aside from the withdrawing of water, in the protoplasmic and nuclear material of the cell so that the element of life no longer exists.

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10. Death from freezing is directly related to the moisture content of the kernel and also to the duration of the exposure to cold. Seed corn maturing in a natural way becomes cold resistant progressively as its moisture content diminishes. Seed corn mortality increases progressively as the duration of the killing temperature is extended. Seed corn samples containing various amounts of moisture were husked from the field and subjected artificially for twenty-four hours to various freezing temperature ranges. After freezing, parts of each sample together with corresponding unfrozen samples were allowed to thoroly cure, after which germination tests were made. The relative germination of the frozen and the unfrozen samples indicates the degree of freezing injury upon the viability as follows:

Temperature Ranges	Moisture Content of Grain (Per Cent)										
	10–15	15–20	20–25	25–30	30–35	35–40	40–45	45–50	50–55	55–60	60–65
Degrees F.	*Relative germination (Per cent)*										
32 to 28	...	...	100	85	75	71	69	...	33	31	0
24 to 20	...	100	96	77	67	13	12	12	6	0	0
16 to 12	...	100	88	34	12	0	0	0	0	0	0
8 to 4	100	98	47	7	0	0	0	...	0	...	...
0 to −5	97	63	0	0	0	0	0	0	0	0	0

Where data are lacking no tests were made.

11. The vitality of corn containing from 15 to 20 per cent of moisture will not be injured by ordinary autumn freezing; and corn with 10 to 14 per cent of moisture will stand the most severe winter temperatures without injury to its germinative power.

12. The kernels upon an ear of corn may vary in moisture content which may explain partial germination of an ear of corn after exposure to freezing temperatures.

13. Ice formation within the kernel is not necessarily fatal to the vitality of the germ.

14. The variation in time of freezing weather together with the great seasonal variation in time of corn maturity makes freezing injury inevitable in occasional years.

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plants before autumn frosts, and (2) by selection of the drier and more mature ears later in the season. Such late varieties may often be advantageously replaced by securing seed of some earlier variety.

17. The conditions are very exceptional in which a satisfactory seed supply cannot be obtained by any of the three following methods: (1) Special early field selection before any likelihood of frost. (2) Selecting seed late in September, or early in October while husking corn in the regular way for early feed. (3) Selecting seed while picking corn to crib in the forepart of the husking season. The relative merits of these three methods will vary according to conditions.

Crib selection of seed corn may be practiced as a last resort if provision for a seed supply by other methods has been overlooked. In years when corn matures well it is a very good and safe practice to select sufficient seed for two years' planting.

18. The viability of seed corn should be ascertained before planting time. This may be done in a general way by a general germination test or by observing the color of the germ. Dark or discolored germs possess little or no vitality. If either of these methods indicate a rather low vitality, a more severe elimination of unsound seed should be made by the individual ear germination test.

19. By a comparison of the yields of corn following years of serious seed corn injury with the average yield of corn for Nebraska during the last 28 years, it seems that predictions of low yields following years of severe seed injury are not justified.

20. Corn harvested early in the fall and given special care in preservation will not outyield seed which has been exposed in the field to the cold winter without special care, provided both are selected for high germinative qualities. As an average for three years, 1915 to 1917, seed corn harvested by special selection from the field in September, November, and March, and given good care after selection, yielded respectively 48.2, 49.6, and 51.2 bushels per acre, while seed saved from the same field during the regular process of husking in November yielded 50.6 bushels per acre.

21. In a comparison of ear types of Nebraska White Prize corn during the four years 1914 to 1917, a long, slender, smooth type of ear yielded 58.8 bushels per acre, which is 0.7 bushels more than the original corn, 7.4 bushels more than the large rough ears, 1.7 bushels more than the short rough ears, and 2.1 bushels more than the short smooth ears. One may conclude that this long, slender, smooth type possesses highly satisfactory

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yielding qualities, which, coupled with its superior germinative ability, makes it a very suitable type to grow.

22. Uniform and varied distribution of seed corn in the field were compared for yield of grain. It was found that there may be much irregularity in stand without a material effect upon yield. As an average for the years 1915 and 1916, a uniform stand of three plants per hill yielded 1.8 per cent more than the mean for the varied distributions in which successive hills contained (a) 1, 2, 3, 4, and 5 plants, (b) 2 and 4 plants, and (c) 1, 3, and 5 plants. This is greater irregularity than results from mechanical variation of corn planters, or from planting 75 per cent germinating seed corn at the rate of four plants per hill.

23. Comparative yields were obtained during two years for corn hills containing one, two, or three plants, when surrounded by hills with three plants. Two-plant hills and one-plant hills yielded respectively 18 per cent and 39 per cent less than a three-plant hill. Fifty per cent of the yield lost in a hill with one missing plant was recovered in the four nearest adjacent hills at right angles. Seventy-two per cent of what was lost in a hill with two missing plants was recovered in the four nearest adjacent hills. Fifty-six per cent of what was lost in a hill with no plants was recovered in the four nearest adjacent hills. It is probable that this recovery also extends at least to the four nearest diagonal hills.

24. An application of the law of chance to the random distribution of sound kernels shows: (1) When 75 per cent germinating seed is planted four per hill, 31.6, 42.3, 21.1, 4.6, and 0.4 per cent of the hills will contain 4, 3, 2, 1, and no sound kernels respectively. These percentages were borne out by actual test. (2) If corn testing 65 per cent germination is planted at the rate of 4 kernels per hill, 17.8, 38.5, 31.1, 11.1, and 1.5 per cent of the hills will contain 4, 3, 2, 1, and no sound kernels respectively. (3) If corn is planted only half of which will grow, at the rate of 5 per hill, 3.1, 15.6, 31.3, 31.3, 15.6, and 3.1 per cent of the hills will contain 5, 4, 3, 2, 1, and no plants.

The actual distribution from a planter will vary somewhat from the above figures for the reason that no mechanical planter will uniformly drop a given number of kernels. The use of low germinating seed corn requires a definite knowledge of the germination percentage which can only be accurately determined by a properly conducted germination test.

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FREEZING INJURY OF SEED CORN

T. A. KIESSELBACH AND J. A. RATCLIFF

INTRODUCTION

Injury to corn for seed purposes by freezing in the fall is of frequent occurrence in Nebraska and thruout much of the corn producing area of the world. The underlying causes of such injury may be (1) late maturity and (2) abnormally early freezing weather. Late maturity may result from (1) late planting, (2) planting of unadapted varieties, and (3) peculiar weather conditions which do not favor early ripening. Undue early freezing may work similar injury to corn that would possess strong vitality under normal weather conditions. When subjected to a severe frost, immature corn suffers a partial or total loss of germinative power.

The object of the investigations in this bulletin has been to determine the conditions under which freezing injury may occur to seed corn: to indicate, if possible, the vital changes in the embryo resulting in such injury; and to point out ways by which seed corn of strong vitality and satisfactory yielding capacity may be obtained.

CHARACTER OF THE CORN EMBRYO AND PROCESS OF GERMINATION

The relation of the embryo to the remainder of the kernel of dent corn may be seen in Figures 1 and 2, which are vertical and cross sections respectively. The starchy and horny endosperm may be distinguished surrounding the embryo, which consists of the plumule, primary root, and scutellum. When placed under heat and moisture conditions proper for germination, enzymes are secreted by the scutellum of a viable corn kernel, which convert the food materials stored in the endosperm into forms which may be used for nourishing the young plant.

In Figure 3 the pericarp or seed coat of a germinating

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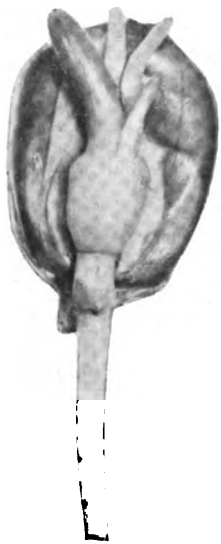
The differentiation of tissues and organs in the embryo of a mature kernel of corn is shown in Figures 5-8. Figure 5 is a cross section thru the plumule surrounded by the scutellum. It may be seen how the young leaves are closely folded or curled up within the plumule. Figures 6, 7, and 8 are vertical sections

(1)

(2)

(3)



(4)

Fig. 1—Vertical section of kernel of dent corn.
Fig. 2—Cross section of kernel of dent corn.
Fig. 3—Growth after 35 hours favorable germination.
Fig. 4—Growth after 55 hours germination showing secondary roots.

1. The material from which these photographs were taken was secured from a yellow variety of ordinary dent corn, Hogue's Yellow Dent. After soaking several kernels in water for about 12 hours, the scutellums were removed and dropped at once into Bowan's Picric formol killing and fixing solution. They remained in this solution for 10 hours. Washing with 70 per cent alcohol was then begun and continued until the material appeared whitish and the alcohol was no longer tinted yellow. The material was then dehydrated in 85, 95, and 100 per cent alcohol, after which it was cleared by bringing it up thru the xylol series. This consists of an alcoholic dilution of xylol in the following proportions: (1) 1 part xylol, 3 parts alcohol; (2) 2 parts xylol, 2 parts alcohol; (3) 3 parts xylol, 1 part alcohol; (4) pure xylol. Infiltration with paraffin was then begun by placing the material, together with a small block of paraffin, in a bottle of pure xylol. It remained in this bottle overnight and was then removed to the paraffin bath, where it remained for about 10 hours, and was

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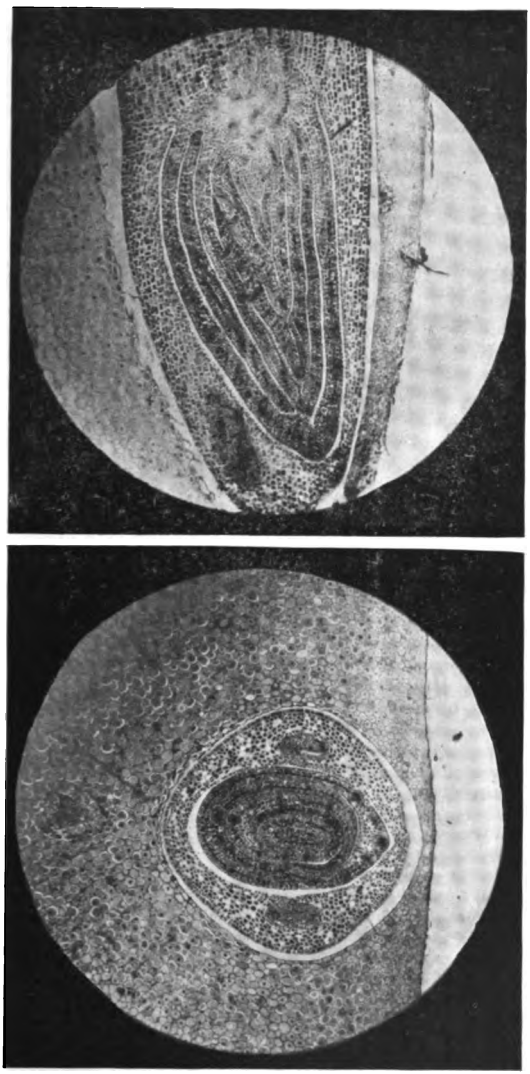

Fig. 5 (upper)—Micro-photograph of cross-section thru plumule of corn embryo

Fig. 6 (lower)—Vertical section thru plumule of corn embryo, showing leaf formation

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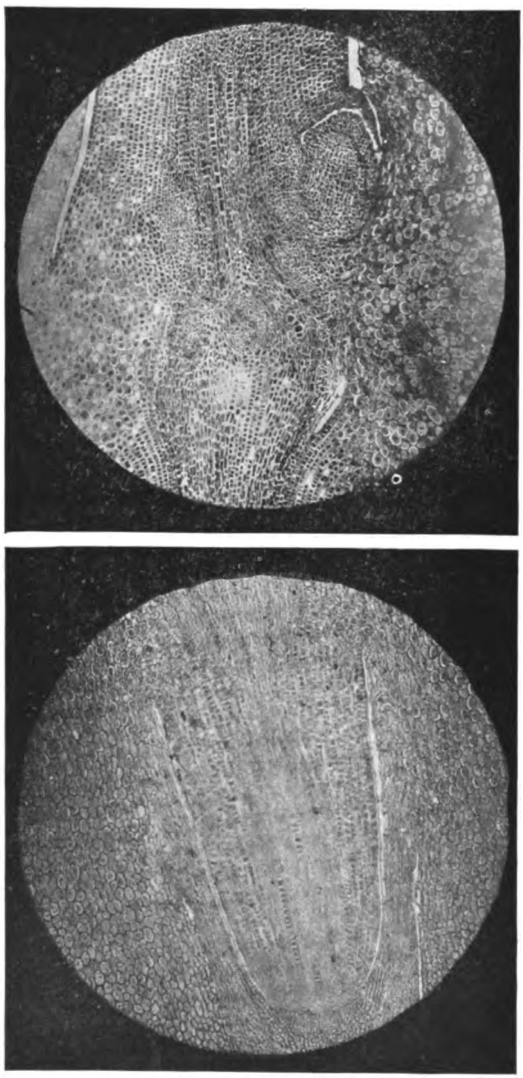

Fig. 7 (upper)—Micro-photograph of vertical section thru the medial area between the plumule and root of a corn embryo. Origin of plumule, primary root and secondary root are visible

Fig. 8 (lower)—Vertical section thru the primary root of a corn embryo

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respectively thru (1) the plumule, (2) the medial area between the plumule and root, and (3) the primary root. The embryo is seen to be a miniature plant, with its vegetative organs fairly distinct.

FREEZING INJURY NOT DUE TO ARRESTED DEVELOPMENT OF THE EMBRYO

The loss of vitality or lack of germinative power occasioned by autumn freezing is not due merely to arrested development of the seed. There is much experimental evidence as well as general observation that corn acquires the power of germination very early in the development of the kernels. Corn

TABLE 1—*Viability of corn harvested at various stages of maturity (1915-1917)*

Date of selection[1]			Weight of 100 kernels			Germination		
1915	1916	1917	1915	1916	1917	1915	1916	1917
			Grams	*Grams*	*Grams*	*Per cent*	*Per cent*	*Per cent*
Aug. 22	Aug. 22	Aug. 2[9]	11.2	15.4	10.0	66	83	92
Aug. 29	Aug. 29	Sept. 4	16.0	19.7	15.4	88	94	94
Sept. 5	Sept. 5	Sept. 11	18.9	22.3	20.0	89	94	99
Sept. 12	Sept. 12	Sept. 18	23.0	25.9	23.8	95	96	99
Sept. 19	Sept. 19	Sept. 25	27.0	28.2	28.6	96	96	99
Sept. 26	Sept. 26	Oct. 2	29.9	31.4	30.9	94	96	99
Oct. 3	Oct. 3	Oct. 9	31.0	32.3	31.0	96	97	100

[1]Corn was in the milk stage at the first selection each year.

Date of selection	Condition of grain	Three year average			
		Days since fertilization[3]	Weight of 100 kernels	Ratio wt. of embryo to wt. of kernel[2]	Germination
			(*Grams*)		(*Per cent*)
Aug. 24	Milk stage	20	12.2	.078	80
Aug. 31	Late milk stage	27	17.0	.105	92
Sept. 7	Roasting ear	34	20.4	.110	94
Sept. 14	Late roasting ear	41	24.2	.103	97
Sept. 21	Denting	48	27.9	.106	97
Sept. 28	Glazing	55	30.7	.112	96
Oct. 5	Mature	62	31.4	....	98

[2]Data for 1917 only.

[3]Pollination occurred on August 1, July 31, and August 10, in 1915, 1916, and 1917 respectively.

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harvested in the "milk" stage has been found to give a fair percentage of germination, and a perfect germination may be secured from seed harvested in the early "dough" stage.

In the seasons of 1915, 1916, and 1917, seed of Hogue's Yellow Dent corn was selected at successive stages of maturity. Immediately after being selected the seed was hung in a dry, airy place and thus cured free from mould or other injury. It was tested for germination late in the winter after becoming air-dry. The results are shown in Table 1.

The average date of pollination during the three years was August 3. This would indicate that the date of fertilization of the ovules was August 4. The average date during the three years of the first selection of corn was August 24, which is approximately twenty days later than the date of fertilization. This first selected seed which had but three weeks development after fertilization weighed only 39 per cent as much, moisture-free, as the best matured seed. Nevertheless, in spite of this premature selection, the earliest gathered seed germinated 80 per cent on an average. The moisture-free weights of 100 kernels for the successive selections were respectively 12.2, 17.0, 20.4, 24.2, 27.9, 30.7 and 31.4 grams. The respective germinations of these seven lots of seed were 80, 92, 94, 97, 96 and 98 per cent.

The germinative ability of very immature corn does not appear to be, as is commonly believed, due to more rapid growth and earlier maturity of the embryo than takes place in the endosperm. The embryo does not mature early with a later filling in of the endosperm. But rather both develop in approximately the same ratio as will appear in Table 2.

TABLE 2—*Relative development of embryo and kernel of Hogue's Yellow Dent corn harvested at various stages of maturity (1917)*

Sample number	Condition of grain	Date of	Days since fertiliza-	Moisture-free weights of			
					100	100 kernels	Ratio of

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For this test, grain harvested at the first six different stages of maturity in 1917 and described in Table 2 was used. The grain was soaked for a short time in water in order to facilitate an accurate separation of the embryo from the rest of the kernel. The relative moisture-free weights of 100 representative kernels and their embryos were determined for each stage of maturity. The moisture-free weights of 100 seeds for each stage were respectively 8.28, 13.45, 17.54, 21.17, 25.10, and 28.04 grams, while the moisture-free weights of the embryos were respectively 0.65, 1.41, 1.94, 2.18, 2.67, and 3.12 grams. The respective ratios of weight of embryos to total weight of

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kernel were .078, .105, .110, .103, .106, and .112. With the exception of the least mature grain, the embryo bore practically a constant relation to the whole kernel regardless of the stage of maturity. For the earliest selection the proportion of embryo was the lowest. This may be accounted for in part by the fact that the initial development of the kernel, prior to fertilization, is a greater factor in the relative weights of the embryo and kernel than at any succeeding time.

When corn was harvested 27 days after fertilization, the scutellum measured 7 millimeters long and the germ from tip of plumule to tip of root was 5 millimeters long. For corn harvested 55 days after fertilization, the length of the scutellum was 9 millimeters, while the germ from tip of plumule to tip of root was 7 millimeters.

MOISTURE CONTENT OF CORN

Since the moisture content of corn is a factor in freezing injury, data were secured to determine the relative moisture content of the embryo and the endosperm. It was thought that this might help to throw some light on the effect of freezing and might perhaps indicate where freezing does its greatest damage. Tests were made with both old and new corn, the results of which are given in Table 3.

Old Corn. The tests with the old corn were of a preliminary nature. In order to insure differences in moisture content, the corn was divided into three lots and treated as follows:

(1) Lot 1 consisted of air-dry corn.

(2) Lot 2 had been placed in a bed of cool, damp soil and allowed to remain for 24 hours.

(3) Lot 3 had been buried in cool, damp soil for 48 hours.

The embryos were then separated from the endosperms of all samples, and moisture determinations made.

The results indicate that in the air-dry condition, the moisture content of the embryo is likely to be as low or lower than in the endosperm. The ratio of the moisture content of the embryo to that of the endosperm was 1.03. In the lot of seed buried in cool, damp soil for 24 hours, the embryos had taken up more moisture than had the endosperms. Here the ratio of the moisture content was 1.36. This difference increased in a still greater degree in the lot buried for 48 hours, the ratio here being 1.77. This represents somewhat the condition of the kernels in the fall before having thoroly cured.

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TABLE 3—*Relative moisture content of embryo and endosperm*

Description of grain	Moisture content		
	Embryo	Endosperm	Ratio embryo to endosperm
OLD CORN	*Per cent*	*Per cent*	
Air-dry	7.91	7.6	1.03
Embedded 24 hours in moist soil	21.37	15.62	1.36
Embedded 48 hours in moist soil	36.81	20.83	1.77
NEW CORN			
Selected from field before dry	31.1	24.1	1.29
Same corn when practically air-dry	10.5	12.9	0.81

New Corn. Twenty-five seed ears were selected in the fall before becoming well dried out. Twenty kernels were removed from each ear and the relative moisture content of the embryo and endosperm determined, giving a ratio of 1.29. When this corn had become practically air-dry, the ratio of the moisture content of the embryo to that of the endosperm was reduced to 0.81.

PHYSICAL EFFECTS OF FREEZING

ICE FORMATION IN KERNELS

It is known that ice is formed in kernels of immature corn when exposed sufficiently to freezing temperatures, and that death frequently follows such exposure. The temperature at which ice is formed within the corn kernel depends very largely upon the moisture content of the kernel. For the most immature seed tested in these experiments, containing 60 to 80 per cent moisture, the freezing point was only slightly below the freezing point of water. On the other hand, no ice formation could be detected in air-dry kernels or in kernels containing less than 18 per cent of moisture, when subjected to the lowest temperature observed: namely 10° F. below zero.

During the freezing process, in case the moisture content was excessive, the water seemed to be drawn from the cells into the larger spaces around the embryo, and about the plumule, the primary root, and the root sheath, and doubtless into the smaller spaces between the cells. In these larger spaces, which may be seen in Figures 1, 2, 5, 6, 7, and 8, the ice would form in a solid sheet around the tissues. In fact, when very moist kernels were exposed to the lower temperatures, the whole kernel

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appeared to be a solid frozen mass. The open spaces in and around the embryo also appeared to be enlarged by the ice formation.

Usually where ice was formed in the kernels, and remained in a frozen condition for practically 24 hours, the vitality was destroyed or weakened. In a few cases, however, ice was noted and still the vitality of the kernel remained unimpaired. Ice formation within the kernel, therefore, even when a coat is formed around or partly around the embryo, does not necessarily mean death. The retention of life depends quite largely upon the duration of the frozen condition. Data regarding the relation between ice formation and injury are given in Tables 5 to 12. In cases where the freezing was severe, frozen kernels were left in a soft, watery condition after thawing. The cells seemed to be unable to absorb the water which had been drawn from them during the freezing process.

EFFECT OF FREEZING ON COLOR OF EMBRYO

The embryo in a kernel of immature or moist corn usually changes from a light or creamy color before freezing to a dark or yellowish brown after freezing. The larger the percentage of moisture, the more sensitive the embryo to cold, and the more readily discoloration takes place. Corn containing 37 per cent moisture and frozen three days at 0° F. showed a slight embryo discoloration in three days and very pronounced darkening in six days after thawing. By looking over the notations regarding embryo color in Tables 5 to 12, it will be seen that the dark color is very closely correlated with loss of vitality. Generally where no loss of vitality resulted from the exposure to the cold, the embryo retained its normal color. The presence of both dark and light embryos on the same ear is associated usually with only a partial loss of vitality, and is frequently due to variation in moisture content of the kernels.

The practice of judging the germinative power of seed corn by the appearance of the embryo therefore seems justified. When loss of vitality has resulted from freezing, this seems to be a fairly safe guide. However, it seems possible that, in very exceptional cases, a loss of vitality might result from some other source without causing a discoloration of the embryo. The method, therefore, can hardly be said to take the place of a germination test.

EFFECT OF FREEZING ON EMBRYONIC TISSUES

Since ice is formed in kernels of immature corn when exposed sufficiently to freezing temperatures, often resulting in

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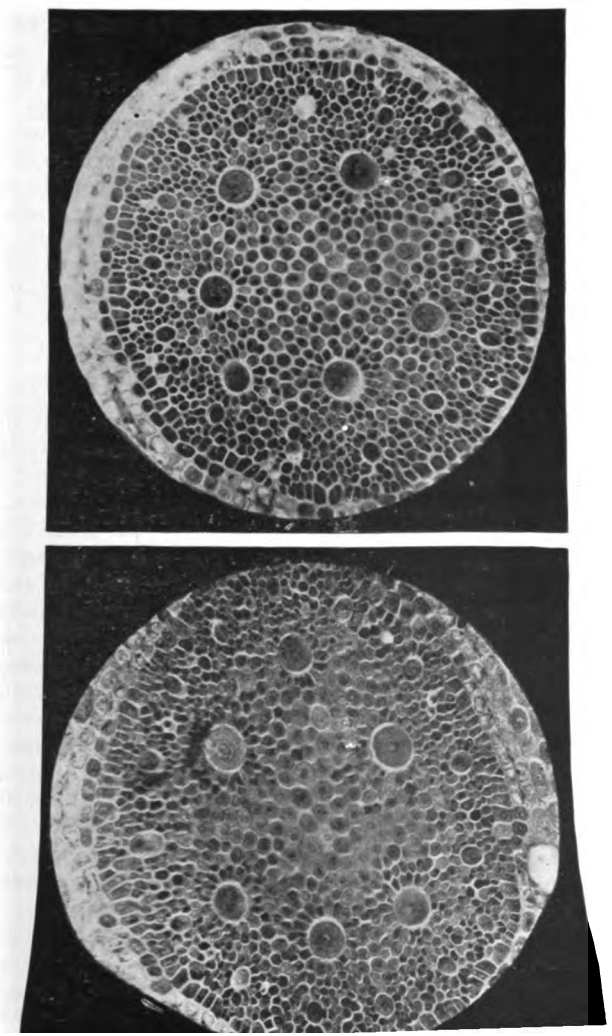

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death, the effect of such ice formation upon the cell structure of the kernel embryo was studied. It was thought that such microscopic studies of frozen embryos might give some clue concerning the cause of death by freezing.

Figures 10 and 11 are microphotographs of cross sections of the primary root of frozen and unfrozen corn embryos respectively. The grain represented by Figure 10 had been frozen for 48 hours at a temperature of 5° F. below zero, and had a moisture content of 35 per cent. Figure 11 represents grain from the same ear which had not been frozen. A large number of frozen and unfrozen grains were sectioned and examined microscopically. No rupture of cell walls or other cytological effect of freezing and ice-formation within the kernels was apparent.

CHEMICAL EFFECTS OF FREEZING

Opportunity did not offer for an exhaustive study of chemical changes involved in freezing injury. However, an ordinary fodder analysis was made in triplicate of both frozen and unfrozen immature grain. A composite sample of shelled corn containing 37 per cent moisture was divided into two parts. One portion was dried immediately. The other was frozen for three days at a temperature of 0° F. At the end of three more days the embryos of the frozen grain had turned dark. This grain was dried and both samples analized. The results are given in Table 4. The differences recorded are probably within the limits of experimental error. Doubtless some chemical change has taken place, otherwise the tissues would not have darkened in color. A germination test of the frozen and unfrozen seed showed 0 and 100 per cent viability.

TABLE 4—*Composition of frozen and unfrozen seed corn*

Character of grain	Composition of moisture-free grain				
	Crude protein	Nitrogen-free extract	Fat	Crude fibre	Ash
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Unfrozen	13.13	78.65	4.54	2.30	1.38
Frozen	12.94	78.61	4.63	2.37	1.45
Ratio of unfrozen to frozen	.985	.999	1.02	1.03	1.05

These analyses were made under the direction of F. W. Upson, Station Chemist.

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PROBABLE CAUSE OF DEATH FROM FREEZING

HISTORICAL REVIEW

There is no doubt but that plant tissues, under certain conditions, die as a result of freezing, but just what freezing does to the vital part of such tissues to bring about death is not fully understood. The theories which have been advanced to explain death by freezing seem to lack sufficient evidence to prove their correctness. Wide differences of opinion are held by various investigators regarding the direct cause of death. At the present time, therefore, any explanation of the phenomenon of death by freezing must be considered as an expression of the probable cause and not as a definite statement of what actually happens. The theories which have been advanced to explain the cause of death from freezing may be grouped as follows: (1) crushing of plant tissues, or rupturing of cell structures, (2) too rapid thawing, (3) desiccation of the protoplasm, (4) physical and chemical disorganization of the protoplasm and other cell contents.

CRUSHING OF PLANT TISSUES OR RUPTURING OF CELL STRUCTURES

As stated by Salmon (1917), the early observers of ice formation within plant tissues, knowing nothing of the cellular structure of plants, attributed death from freezing to rending or crushing of the tissues.

In 1737 Du Hamel and Buffon proposed that death resulted from a rupturing of the cell walls due to the expansion which accompanies ice formation. The same opinion was held by Geopert (1830) who discovered ice within the cells and also outside the cells in the intercellular spaces. Sachs (1860) found that ice was sometimes formed within the cells, and Müller-Thurgau (1886) concludes that ice is formed within the cells only in case of very large size, or very rapid freezing.

Supercooling followed by ice formation, and very rapid cooling are more injurious to plant tissues than slow cooling, according to Mez (1905). Neither supercooling nor rapid cooling give the water in the cells time to escape and ice is, therefore, formed within the cells. In each of the above cases where ice was formed within the cells, whether it was the result of slow or rapid cooling, or whether the tissues had been supercooled, the investigators seemed to think that the increase in volume probably worked some injury to the cell walls.

Plant tissues containing a large percentage of water, such as turgid leaves, and young, growing twigs are especially sub-

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ject to injury from ice formation. Wiegand (1906) found the upper and lower parts of leaves entirely separated by layers of ice, and also the outer layers of twigs separated from the inner by a sheet of ice. The injury resulting from the freezing of green plants is due to the change in volume when the water in the plant freezes, according to Gassner and Grimme (1913), and not to any special effect upon the plant cells. The result of this increase in volume is a tearing of the tissues, or a breaking up of the cell structure. This form of injury is recognized by Chandler (1913) as being entirely possible, for he speaks of the tearing of tissues due to the tension developed at low temperatures.

While studying the influence of the temperature of liquid hydrogen on the germinative power of seeds, Thiselton-Dyer (1899) suggest that the sudden vacuum caused within the seeds by immersing them in liquid hydrogen might possibly produce physical ruptures which would weaken or destroy their vitality. Adams (1905) also mentions the possibility of injury from this source, but thinks the vacuum too small to be of any serious consequence. He concludes, further, that the intercellular spaces in seeds are very small, and that in moist seeds, after freezing has gone on for some time, these spaces become filled with a solid mass of ice. Then if the temperature is still further lowered, more ice is formed, and it is likely that complete rupture takes place, causing a separation of the cells from each other.

TOO RAPID THAWING

Many have thought that the phenomenon of death from freezing is not due directly to freezing but to the rate or rapidity of thawing. Sachs (1860) an early investigator, was an ardent supporter of this belief, and for many years his work was considered conclusive. Later, Müller-Thurgau (1886) pointed out inaccuracies in his work and showed by experiments with a large number of plants that there was no difference in the amount of killing whether tissues were thawed rapidly or slowly, except in the case of ripe apples and pears. It was found also by Molisch (1897) and Chandler (1913) that in general the rate of thawing is not related to the amount of killing at a given temperature, the exceptions to this rule being the leaves of lettuce, leaves of Agave americana, and ripe apples and pears. In arguing against the theory that plant tissues are killed by the rate of thawing rather than by freezing, Detmer (1893) mentions several mosses which can remain in a hard frozen condition for a long time without showing any

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material damage after thawing whether the latter process takes place slowly or suddenly.

Coming back again to the belief held by Sachs, it is stated by Adams (1905) that during the freezing process water is drawn from the cells and solidified in the intercellular spaces, and that if freezing has not gone too far, and if thawing be gradual, the ice melts and is absorbed again by the cells and no injury results. In discussing the effect of freezing on cultivated plants, Galloway (1895) makes a similar statement. Brown and Escombe (1897-1898) while trying to determine the influence of very low temperatures on the germinative power of seeds, express the opinion that the vitality of the seeds was injured more by rapid thawing than by gradual thawing.

DESICCATION OF THE PROTOPLASM

Probably the most generally accepted theory of the cause of death from freezing has been, that death results from desiccation of the protoplasm when water is drawn from the cells into the intercellular spaces in the process of ice formation. It was early discovered that when plant tissues freeze, water is drawn from the cells and ice crystals are formed in the intercellular spaces. Geoppert (1830) and Sachs (1860) both observed these phenomena but reached rather different conclusions as to the real cause of death. Geoppert thought that death resulted as a direct effect of freezing and that death occurred while the tissues were still in a frozen condition; while Sachs thought that death occurred during the thawing process. That water is withdrawn from the cells during the process of freezing and that ice crystals are usually formed in the intercellular spaces, and only rarely within the cells, was again declared by Müller-Thurgau (1886) and also by Molisch (1897); the latter observing the movement of water and the formation of ice crystals in plant tissues under the microscope. Both of these men were of the opinion that death from freezing is due to the withdrawal of water from the cells, and that it is essentially the same thing as death from desiccation. Müller-Thurgau went so far with his work as to determine the amount of water drawn from cells by freezing. For apple he found that at a temperature —13 degrees C., 63.7 per cent had been lost, and at —15.2 degrees C., 79.2 per cent of the water had passed from the cells.

In regard to the effect which the removal of water may have upon the cell contents, Wiegand (1906) thinks it is probable that death from freezing is caused by drying out of the proto-

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plasm beyond the critical water content. Maximow (1908) agrees with Müller-Thurgau and Molisch in that the withdrawal of water during the freezing process is the killing factor. He concludes, however, that the withdrawal of water is limited to the plasma membrane, and that this membrane is the part of the cell which is injured and that as long as a film of water can be kept in contact with this membrane no injury takes place. Matruchot and Molliard (1901) also believed that water was drawn from the protoplasm and nuclear material of the cell in the process of freezing and that this continued until they contained less than the minimum required to maintain vitality. Protoplasm, in order to retain its vitality, according to Ewarts (1897), requires from 2 to 3 per cent of water. Adams (1905) contends that if these theories be true the same argument should hold for dry seeds which contain about 12 per cent of water. But dry seeds are not killed by freezing. Hence some other explanation must be found.

PHYSICAL AND CHEMICAL DISORGANIZATION OF THE PROTOPLASM AND OTHER CELL CONTENTS

Many who have sought to determine the cause of death by freezing have concluded that freezing produces certain physical and chemical changes in the protoplasm and other cell contents, and that these changes result in death of the living matter. In harmony with this view, Detmer (1893) states, "In consequence of the disorganization of the protoplasm the cellular fluids leave the plasma; at the same time the nature of the hyloplasmic layers undergoes a complete change and they are now pervious to many substances which in a normal condition they did not permit to pass. This is the cause of the discoloration of frozen plants and of the phenomenon that pieces of frozen red beet, if put into water, readily part with coloring matter and sugar, while the living cells tenaciously retain these substances." Becquerel (1905), in studying the action of liquid air on the life of seeds, found that if sufficient moisture was present in the tissues the cold disorganized the protoplasm and nucleus, making germination impossible. Galloway (1895) also contributed to this same idea, for he concluded that a freezing temperature may be sufficiently low to cause a chemical disorganization of the living substance and that the part of the plant where this takes place dies. Gorke (1906) and Schaffnit (1912) both found that freezing precipitated certain proteids from the cell sap and that the ease with which these proteids are precipitated bears some relation to the hardiness of the plant. Precipitation of the proteids, therefore, according to their interpretations, is

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the cause of death. Chandler (1913), however, does not agree with this. He found no precipitation of proteids in the sap of young twigs of apple, plum, or pear and only slight traces of it in other plants. He calls attention to the fact, however, that frozen plant tissues, soon after thawing, take on a brown color and a soft watery condition, and that evaporation goes on much more rapidly from the surface of such tissues than it does from the surface of similar tissues which have not been frozen.

PERSONAL INTERPRETATION

One of the objects of the experiments reported in this bulletin was to determine the effect of freezing upon the cellular structure of the corn kernel and especially of the embryonic tissues, for the purpose of indicating the true cause of death resulting from freezing. It was thought that if death was due to some mechanical injury to the tissues or to disorganization of the cellular material, it would be indicated by a separation of the cells from each other, or by broken down cell walls, or by a difference in the appearance of the cell contents. With this idea in mind, careful studies were made both of frozen and unfrozen sections of embryonic material, permanently mounted and stained sections being used. Mechanical injuries of the cell structure or rupturing of the tissues were sought for with considerable care, as it was thought that these probably were the primary causes of the loss of vitality.

No such injuries were found, however, in the embryonic tissues of the kernel. It was thought, then, that if such injuries result at all from freezing, they should occur in the tender tips and stems of young corn seedlings. Sections of frozen tips and stems of such material were, therefore, studied. Even in this tender, rapidly growing material no rupturing or breaking down of the cellular structure could be detected. However, from the observations of Wiegand (1906), Chandler (1913), and others, there can be no doubt but that a rupturing of plant tissues sometimes results from freezing; but from the evidence at hand, it must be concluded that death from freezing is not due to mechanical injuries but to some other cause.

The protoplasmic and nuclear material of the cells of frozen and unfrozen tissues were studied microscopically; the same material being used for this as was used while searching for mechanical injuries. So far as was observed, no disorganization or change of appearance was detected. It should be stated here, however, that observations of the cellular material were not very extensive, and the material used for study had

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been placed in the killing and fixing solution while still in a frozen condition. It is probable, therefore, that killing took place before there could be any material readjustment of the living matter. It was thought, however, that the change in color of embryonic tissues and other plant tissues and the soft watery condition characteristic of all tissues which have been frozen to death indicates that some physical or chemical change has been brought about. Even tho the change in color of the embryo of a corn kernel after freezing may be due to the action of some enzyme or of bacteria, the fact remains that a change has been effected which makes possible such action. The instance cited by Detmer (1893) of pieces of frozen red beet giving up their coloring matter and sugar when placed in water, while these substances are tenaciously retained by the unfrozen material, adds some evidence of a physical or chemical change. The soft, watery condition of plant tissues after freezing also appears to be the result, at least in part, of disorganization of the cellular material, and not entirely to a withdrawal of the water from the cells. That this is true is drawn from the observations of Müller-Thurgau (1886) and Mez (1905) regarding the formation of ice within the cells when the tissues are supercooled or frozen rapidly. If the extraction of water from the cells was the only cause of the watery condition in question, tissues which are frozen rapidly or supercooled, so that crystalization takes place largely in the cells, should not exhibit this condition. But this water-soaked condition is characteristic of frozen tissues whether the freezing has been done rapidly or slowly.

Altho chemical changes have not been established by chemical analysis, it seems certain that changes take place within the protoplasmic and nuclear contents as a result of freezing and that these changes make it impossible for the processes of life to continue.

The withdrawal of water from the cells by freezing has been considered by many as the cause of death. It was noted that in moist corn kernels, water was withdrawn from the tissues and ice formed in masses and sheets in space surrounding or separating different tissues, and that death usually accompanied such ice formation. It was also noted that air-dry corn, which contains from 10 to 12 per cent of moisture, was not frozen, at least its vitality was not injured, and according to the observations of Brown and Escombe (1897-8), Adams (1905), Thiselton-Dyer (1899), and others it was not injured even when exposed for several hours to the temperature of liquid air or

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liquid hydrogen. According to Müller-Thurgau (1886), apples lost 63.8 per cent of their moisture when frozen at —4.5 degrees C.; 36.2 per cent of the total water, therefore, remained in the cells. Kernels of corn which contain a large percentage of water will freeze at this temperature and die. If the moisture content of the cells of a kernel of corn were reduced to 30 or even 20 per cent at this temperature, the vitality should remain uninjured, so far as moisture is concerned. Dry seeds contain only 10 to 12 per cent of moisture, yet they retain their vitality, and a still further reduction in the moisture content can be made without injury. Ewarts (1897) shows that the fatal minimum moisture content of protoplasm is 2 or 3 per cent. The theory is, then, that as the cooling goes on, more and more water is withdrawn until less than this amount remains in the cell, and death results. This should also hold true for dry seed which contain 10 or 12 per cent of water, but these are not injured by such freezing. An example may also be taken from Table 9, where corn containing 20.5 per cent of moisture was entirely killed, while corn containing 16.3 per cent of moisture showed no injury. The freezing evidently did not reduce the moisture content in the former case more than 2 or 3 per cent, yet the vitality was destroyed. It does not seem probable that the removal of so small an amount of water would cause death. It seems more probable, however, that the small difference in moisture content was sufficient to permit disorganization of the protoplasm in the one case, while in the other it remained unaffected.

The rate of thawing and its relation to killing was not studied. The results which have been obtained and reported by Müller-Thurgau (1886), Molisch (1897), and Chandler (1913) seem to indicate quite clearly that it has very little to do with the amount of killing. It can hardly be considered, therefore, as an important factor in bringing about the death of frozen tissues.

EFFECTS OF FREEZING UPON THE VIABILITY OF SEED CORN

Ordinary freezing temperatures do not injure mature, dry corn, but it is always the immature or damp corn that is injured by freezing. It was proposed, therefore, to determine at what temperature freezing and loss of vitality take place in corn at different stages of maturity as indicated by differences in moisture content.

The effect of freezing upon the germinative qualities of seed corn has been tested experimentally under two sorts of

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conditions: (1) Artificial freezing under control conditions; and (2) natural freezing of corn standing in the field under prevailing natural conditions.

VITALITY OF CORN FROZEN UNDER CONTROL CONDITIONS

APPARATUS

The low temperatures used in these experiments were secured under control conditions by the use of a freezing mixture of salt and ice. By mixing the salt and ice in the proportion of one part of salt to two parts of ice a temperature of —5° F. was secured. In order to secure the various ranges of temperature and to maintain those temperatures for several hours, two different devices were used.

For temperatures above zero, an insulated freezing box was made. The essential parts of this box are: (1) A compartment for containing the freezing mixture. This was large enough to hold about two hundred pounds of crushed ice. (2) A compartment for containing a strong salt solution and a freezing cell. This compartment or chamber was large enough to hold twenty gallons of brine. (3) A freezing cell into which the material was put for freezing. This cell was cylindrical in shape 5 inches in diameter and 18 inches deep, with capacity for sections from 30 ears of corn. (4) A series of connected cells in the freezing mixture compartment. This series of cells was connected with the brine chamber in such a way as to allow the cells to fill with brine. (5) A pump for circulating the brine thru the cells and back into the brine chamber. (6) A thermometer to indicate the temperature in the freezing cell.

The working principle of this device was somewhat as follows: The freezing mixture of salt and ice was packed around the series of brine cells. This reduced the temperature to 0° F. or below in this chamber, and cooled the brine in the cells. The brine was made strong enough so that it would not freeze at this temperature. The corn was then placed in the freezing cell, the lid closed, and the thermometer inserted. When all was ready, the pump, operated by an electric motor, was started and the chilled brine from the series of cells was forced into the large brine chamber and other brine drawn into the cells to cool. By this method the twenty gallons of brine

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Fig. 12—Freezing apparatus in which salt solution circulates
a. Connected cells where freezing mixture is placed
b. Spaces between cells where freezing cell is inserted
c. Place where freezing salt solution
d. Compartment containing salt thermometer
e. Lid with hole for inserting
f. Freezing cell
g. Pump for circulating salt solution

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PROPERTIES OF SOLUTION OF SALT—*From J. E. Siebel, Compend of Mechanical Refrigeration and Engineering*

Percentage of salt by weight	Pounds of salt per gallon of solution	Weight per gallon 39°F.	Freezing point Fahrenheit
	(*Pounds*)	(*Pounds*)	(*Degrees*)
0	0	8.35	32
1	0.084	8.40	30.5
2	0.169	8.46	29.3
2.5	0.212	8.50	28.6
3	0.256	8.53	27.8
3.5	0.300	8.56	27.1
4	0.344	8.59	26.6
5	0.433	8.65	25.2
6	0.523	8.72	23.9
7	0.617	8.78	22.5
8	0.708	8.85	21.2
9	0.802	8.91	19.9
10	0.897	8.97	18.7
12	1.092	9.10	16.0
15	1.389	9.26	12.2
20	1.928	9.64	6.1
24	2.376	9.90	1.2
25	2.488	9.97	0.5
26	2.610	10.04	—1.1

For securing the temperatures below zero a different sort of device was used. This consisted simply of a barrel with a small keg placed inside of it. The space around the keg was filled with sawdust. The freezing cell from the other apparatus was placed in the keg and the freezing mixture packed around it until the keg was full. It was then covered well with burlap and a tight lid put on the barrel. By this method a temperature of —5° could be maintained almost constant in the freezing cell thruout the twenty-four hours.

After the corn was frozen it had to be dried quickly in order to keep it from becoming mouldy. A screen wire box

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days each. The same variety of corn (Hogue's Yellow Dent) was used for each planting. Thus ears of the same variety but of different degrees of maturity could easily be selected at any one time in the fall. As soon as the early planted corn was well matured, selections were made from each plot. These selections included ears representing four stages of maturity. The first stage was green corn, much greener than would ever be selected for seed. In fact, this represented the "roasting ear" stage of development. The ears of the fourth stage were the most mature ones that could be found in the field at the time. The starchy part of the kernels was beginning to appear dry and mealy when cut with a knife. The horny part of the kernels also had begun to appear hard and brittle. As the season advanced, the corn secured for the fourth stage became drier and more mature, while the selections for the first stage remained very much the same thruout the season. The second and third stages represented intermediate degrees of maturity between the first and the fourth.

METHOD OF HANDLING

The ears selected were taken at once from the field and treated in the following manner: (1) A part of the tip was removed and discarded. (2) Each ear was divided into three sections. The section next to the tip was used for a moisture test, and the adjacent section for an immediate freezing test. The remaining part of the ear was stored in a dry, airy place where it would have a chance to cure thoroly. This part together with the frozen section was kept in storage for four or five months. At the end of that time germination tests were made.

MOISTURE TESTS

Moisture tests were made of the grain on each ear. The samples were dried at 100° to 110° C., and the percentage of water was calculated, using the green weight as a basis. In all cases the sample for the moisture determination was taken next to, or from the part of the ear which was to be subjected to the freezing temperature. The percentage of moisture thus secured represented very closely the actual moisture content of the corn placed in the freezing test.

SUBJECTION TO FREEZING TEMPERATURES

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of twenty-four hours. That is, one lot of ears consisting of four or five from each stage of maturity was subjected to a temperature ranging from 28° to 32° F. A similar lot was subjected to a range from 20° to 24° F.; another from 12° to 16° F.; another from 4° to 8° F.; and still another from —5° to 0° F. The ears were placed in the freezing chamber within an hour or two after being brought from the field. The temperature was then lowered to the desired degree as quickly as possible. For the higher temperature and for the range below zero, from one to two hours were required, while for the intermediate temperatures three to four hours were required. The difference in length of time was due to the difference in the degree of cold and in the apparatus used. After exposure to the cold, no attempt was made to bring the corn gradually to a higher temperature, but it was removed from the freezing chamber and exposed at once to the air temperature. It was then placed in a screen wire box which was set in a warm, dry, airy place. Here the ears dried quickly, so that but little loss from damp or mouldy seed was experienced. All freezing tests except those in a special experiment in 1916 were made with ear corn from which the husks had been removed.

GERMINATION

After the samples had been subjected to freezing temperatures and had remained in storage until thoroly cured, germination tests were made from each section. The corresponding section from the same ear which had not been exposed to the freezing temperature was placed in germination test at the same time. The percentage germination of the latter serves as a standard with which the germinative ability of the exposed part may be compared, or by which the effect on vitality of exposure to the low temperatures may be measured.

The germination tests were made between blotting papers on moist sawdust. Wet burlap was used as a covering over the blotting paper. The germination boxes were placed in a warm incubator having a temperature of 30° C. and allowed to remain for six days, when the counts were made. The germination percentages unless otherwise stated mean perfect germination with prospects for normal development.

OBSERVATION OF ICE IN SEED

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occurs in corn containing different amounts of moisture. By freezing is meant here, the formation of ice crystals within the kernel. The observation was made by cutting thru the small end of the kernel, and by scraping the cut surface, or by digging in and around the embryo with a knife. The observation was made immediately after removing the sample from the freezing chamber.

The occurrence of ice crystals was not noted in all of the tests. In those tests where notes were taken all of the ears were examined. In the tables, the presence or absence of ice in all cases where examinations were made is indicated. It was very difficult to detect the ice in the samples of low moisture content because of the small amount present and because of rapid thawing. There is a possibility, therefore, that ice crystals may have been present in some of the samples and yet escaped detection. The presence of ice is discussed in connectoin with the following investigations.

COLOR OF EMBRYO

Notes were also taken regarding the color of the embryo at the time when the germination tests were made. The color was designated as either dark or light. The light color represents the natural color of a normal embryo. On the other hand, a dark or brownish color is quite characteristic of a frozen embryo. In a number of cases a part of the kernels on an ear would have a dark embryo and part of them a light embryo. Usually this condition was found to be associated with only a partial loss of vitality.

For convenience of comparison, all ears which were subjected to a given range of temperature are grouped in the tables according to moisture content, a range of 5 per cent being allowed for each group. In all cases where there were more than one sample in a given moisture range an average for the group is given.

RELATION BETWEEN MOISTURE CONTENT AND INJURY AT VARIOUS DEGREES OF FREEZING

FREEZING AT TEMPERATURE RANGE OF 32° TO 28° F.

The data for all the samples frozen at the temperature range of 32° to 28° F. are given in Table 5. It would seem from the data in this table that the vitality of corn with a high moisture content may be seriously injured or almost totally destroyed by such a light freezing as is represented by the above temperature range when prolonged for a period of 24 hours.

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TABLE 5—*Effect of freezing temperatures on germination of corn differing in moisture content (1913 and 1914)*

Temperature range 32° to 28°F.

Moisture range	Moisture in grain	Germination			Ice observed in grain	Embryos dark or light
		Normal grain	Frozen grain	Ratio of normal to frozen		
Per cent	*Per cent*	*Per cent*	*Per cent*			
80 to 85	84.3	0	0	0:0	*	Dark
	80.7	0	0	0:0	*	Dark
Average	82.5	0	0	0:0		
70 to 75	72.1	100	0	100:0	Ice	Dark
	71.8	100	0	100:0	Ice	Dark
	71.0	100	0	100:0	*	Dark
Average	71.9	100	0	100:0		
65 to 70	69.2	20	0	100:0	*	Dark
	69.2	100	0	100:0	*	Dark
	68.4	100	0	100:0	*	Dark
	68.3	87	0	100:0	Ice	Dark
	67.2	100	20	100:20	*	Dark
	66.5	100	0	100:0	Ice	Dark
	66.2	100	0	100:0	Ice	Dark
	65.2	100	0	100:0	*	Dark
Average	67.5	88.4	2.5	100:2.8		
60 to 65	62.8	100	0	100:0	*	Dark
	61.1	100	0	100:0	*	Dark
Average	62.0	100	0	100:0		
55 to 60	59.7	100	50	100:50	*	*
	57.7	100	0	100:0	*	Dark
	56.6	100	30	100:30	*	Light
	55.2	87	37	100:43	Ice	Dark and light
Average	57.6	96.8	29	100:31		
50 to 55	54.7	90	75	100:80	Ice	Dark and light
	54.0	100	0	100:0	*	Dark
	53.9	100	0	100:0	Ice	Dark
	52.3	100	87	100:87	Ice	Dark and light
	51.2	100	0	100:0	Ice	Dark
Average	53.2	98	32.4	100:33		

*No observations made.

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TABLE 5 *(Continued)—Effect of freezing temperature on germination of corn differing in moisture content (1913 and 1914)*

Temperature range 32° to 28°F.

Moisture range	Moisture in grain	Germination			Ice observed in grain	Embryos dark or light
		Normal grain	Frozen grain	Ratio of normal to frozen		
Per cent	*Per cent*	*Per cent*	*Per cent*			
40 to 45	45.8	100	100	100:100	*	*
	44.1	100	100	100:100	*	*
	44.1	100	40	100:40	*	Dark
	44.0	100	40	100:40	*	Dark
	42.4	75	50	100:67	None	Light
Average	44.1	95	66.0	100:69		
35 to 40	39.5	100	55	100:55	*	Light
	38.9	100	20	100:20	*	Dark
	38.7	60	60	100:100	*	Light
	38.6	100	50	100:50	*	*
	37.1	100	58	100:58	*	Light
	36.3	100	80	100:80	*	Light
	36.1	100	85	100:85	None	Light
	35.9	100	87	100:87	None	Light
	35.8	100	100	100:100	*	Light
	35.6	100	100	100:100	*	*
	35.1	100	100	100:100	*	Light
Average	37.1	96.4	65	100:71		
30 to 35	33.7	100	100	100:100	*	*
	33.1	90	35	100:39	None	Light
	30.6	100	100	100:100	*	Light
	30.3	100	60	100:60	*	Dark and light
Average	31.9	97.5	73.8	100:75		
25 to 30	28.3	100	100	100:100	*	*
	28.2	100	80	100:80	*	Light
	28.1	60	60	100:100	*	Dark
	27.8	100	100	100:100	*	Light
	27.3	100	87	100:87	None	Light
	27.3	80	80	100:100	*	Light
	26.4	100	20	100:20	*	Dark and light
	25.7	100	100	100:100	*	Light
Average	27.4	92.5	78.4	100:85		

*No observations made.

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TABLE 5 *(Continued)—Effect of freezing temperatures on germination of corn differing in moisture content (1913 and 1914)*

Tempera ure range 32° to 28°F.

Moisture range	Moisture in grain	Germination			Ice observed in grain	Embryos dark or light
		Normal grain	Frozen grain	Ratio of normal to frozen		
Per cent	*Per cent*	*Per cent*	*Per cent*			
20 to 25	21.4	100	100	100:100	*	*
	21.2	100	100	100:100	*	Light
	20.3	100	100	100:100	*	*
	20.1	100	100	100:100	*	Light
Average	20.8	100	100	100:100		

*No observations made.

The ears with the lowest moisture content were uninjured, while many of those of intermediate moisture content showed more or less loss of vitality. It will also be noted that ice crystals were found in the kernels containing 50 per cent or more of moisture, while no ice was noted in kernels containing less than this amount.

All kernels with high moisture content showed dark embryos. The change in embryo color and in ice formation to no ice, together with the germination tests, seems to indicate that the transition from a critical moisture content to one where little or no injury resulted took place between 50 and 40 per cent.

TEMPERATURE 24° TO 20° F.

Table 6 contains the data for all the freezing tests in which

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TABLE 6—*Effect of freezing temperatures on germination of corn differing in moisture content (1913 and 1914)*

Temperature range 24° to 20°F.

Moisture range	Moisture in grain	Germination			Ice observed in grain	Embryos dark or light
		Normal grain	Frozen grain	Ratio of normal to frozen		
Per cent	*Per cent*	*Per cent*	*Per cent*			
75 to 80	79.0	100	0	100:0	*	Dark
	76.5	100	0	100:0	*	Dark
	75.9	62	0	100:0	Ice	Dark
	75.7	75	0	100:0	Ice	Dark
Average	76.8	84.2	0	100:0		
70 to 75	73.5	100	0	100:0	*	Dark
	70.6	87	0	100:0	Ice	Dark
	70.2	100	0	100:0	*	Dark
Average	71.4	95.7	0	100:0		
65 to 70	68.8	100	0	100:0	Ice	Dark
60 to 65	61.5	100	0	100:0	Ice	*
	60.4	100	0	100:0	Ice	Dark
Average	61.0	100	0	100:0		
55 to 60	58.9	100	0	100:0	*	Dark
	58.6	100	0	100:0	*	Dark
	57.4	100	0	100:0	Ice	Dark
Average	53.3	100	0	100:0		
50 to 55	53.9	100	0	100:0	Ice	Dark
	51.3	100	12	100:12	Ice	Dark
Average	52.6	100	6.0	100:6		
45 to 50	49.6	100	25	100:25	Ice	*
	45.1	100	0	100:0	Ice	Dark
Average	47.4	100	12.5	100:12		
40 to 45	43.1	100	25	100:25	Ice	*
	44.9	100	0	100:0	Ice	Dark
	42.4	100	37	100:37	Ice	Dark and light
	42.0	100	0	100:0	*	Dark
	41.7	100	0	100:0	*	Dark
	41.0	100	12	100:12	Ice	Dark
Average	42.5	100	12.3	100:12		

*No observations made.

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TABLE 6 *(Continued)—Effect of freezing temperatures on germination of corn differing in moisture content (1913 and 1914)*

Temperature range 21° to 25°F.

Moisture range	Moisture in grain	Germination			Ice observed in grain	Embryos dark or light
		Normal grain	Frozen grain	Ratio of normal to frozen		
Per cent	*Per cent*	*Per cent*	*Per cent*			
35 to 40..	40.0	100	0	100:0	Ice	*
	39.4	100	0	100:0	*	Dark
	35.5	100	40	100:40	*	Light
Average..	38.3	100	13	100:13		
30 to 35..	33.8	100	0	100:0	*	Dark
	30.9	100	100	100:100	None	*
	30.7	100	100	100:100	None	*
Average..	31.8	100	66.6	100:67		
25 to 30..	28.8	100	20	100:20	*	Dark
	28.8	100	75	100:75	Ice	Dark
	28.3	100	50	100:50	Ice	Dark and light
	27.5	100	100	100:100	None	*
	27.4	100	100	100:100	*	Light
	27.1	100	100	100:100	*	Light
	26.2	87	87	100:100	Ice	Light
Average..	27.7	98.1	76.0	100:77		
20 to 25..	22.6	100	100	100:100	*	Light
	22.1	100	87	100:87	None	Light
	20.4	100	100	100:100	None	*
Average..	21.7	100	95.7	100:96		
15 to 20..	17.0	100	100	100:100	*	Light

*No observations made.

TEMPERATURE RANGE 16° TO 12° F.

The data for the corn subjected to a temperature ranging from 16° to 12° F. are given in Table 7. It will be noted from this table that the fatality range is very much the same as

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TABLE 7.—*Effect of freezing temperatures on germination of corn differing in moisture content (1913 and 1914)*

Temperature range 16° to 12°F.

Moisture range	Moisture in grain	Germination			Ice observed in grain	Embryos dark or light
		Normal grain	Frozen grain	Ratio of normal to frozen		
Per cent	*Per cent*	*Per cent*	*Per cent*			
65 to 70	67.2	100	0	100:0	Ice	*
60 to 65	61.8	100	0	100:0	*	Dark
55 to 60	60.0	100	0	100:0	Ice	*
50 to 55	54.6	100	0	100:0	*	Dark
45 to 50	48.9	100	0	100:0	*	Dark
	47.7	100	0	100:0	Ice	*
	48.5	100	0	100:0	*	Dark
	47.6	100	0	100:0	*	Dark
	46.2	100	0	100:0	*	Dark
Average	48.0	100	0	100:0		
40 to 45	44.5	80	0	100:0	*	Dark
35 to 40	39.6	100	0	100:0	*	Dark
	38.5	100	0	100:0	*	Dark
	36.8	100	0	100:0	*	Dark
	35.9	75	0	100:0	Ice	*
Average	37.7	93.8	0	100:0		
30 to 35	34.6	100	0	100:0	*	Light
	34.1	100	0	100:0	Ice	*
	33.2	100	0	100:0	*	Dark
	31.5	100	60	100:60	*	Dark and light
	31.2	100	0	100:0	Ice	*
Average	32.9	100	12.0	100:12		
25 to 30	29.7	100	20	100:20	*	Dark and light
	28.9	100	0	100:0	*	Light
	26.5	100	100	100:100	*	Light
	26.4	100	60	100:60	*	Dark and light
	26.4	100	60	100:60	*	Light
	26.1	100	0	100:0	None	*
	26.0	100	0	100:0	*	Dark
Average	27.1	100	34.3	100:34		

*No observations made.

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TABLE 7 *(Continued)—Effect of freezing temperatures on germination of corn differing in moisture content (1913 and 1914)*

Temperature range 16° to 12°F.

Moisture range	Moisture in grain	Germination			Ice observed in grain	Embryos dark or light
		Normal grain	Frozen grain	Ratio of normal to frozen		
Per cent	*Per cent*	*Per cent*	*Per cent*			
20 to 25..	24.4	100	40	100:40	*	Light
	23.9	100	100	100:100	*	Light
	22.7	100	100	100:100	*	Light
	22.1	100	100	100:100	*	Light
	21.5	100	100	100:100	*	Light
	21.4	100	100	100:100	*	Light
	21.0	100	100	100:100	*	Light
	20.8	100	100	100:100	*	Light
	20.8	100	50	100:50	None	*
Average..	22.1	100	87.8	100:88		
15 to 20..	19.8	100	100	100:100	*	Light
	18.1	100	100	100:100	*	Light
	17.8	100	100	100:100	*	Light
	17.2	100	100	100:100	*	Light
	17.0	100	100	100:100	*	Light
	15.5	100	100	100:100	*	Light
	15.3	100	100	100:100	*	Light
Average..	17.2	100	100	100:100		

*No observations made.

noted thruout the range. The transition here from a fatal moisture content to one free from injury seems to have occurred between 30 and 25 per cent. Below this range, no definite injury appears to have resulted from the exposure as indicated by the percentage germination or by the color of the embryo.

TEMPERATURE RANGE 8° TO 4° F.

The data for the freezing tests in which a range of temperature from 8° to 4° F. was used are given in Table 8. In these tests, freezing and loss of germinative ability took place at a lower moisture content than in any of the previous tests. The transition here from injury to no injury seems to have occurred between 25 and 19 per cent moisture content, and but little loss of vitality appears to have resulted where the corn contained less than 20 per cent of moisture.

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TABLE 8—*Effect of freezing temperatures on germination of corn differing in moisture content (1913 and 1914)*

Temperature range 8° to 4°F.

Moisture range	Moisture in grain	Germination			Ice observed in grain	Embryos dark or light
		Normal grain	Frozen grain	Ratio of normal to frozen		
Per cent	*Per cent*	*Per cent*	*Per cent*			
50 to 55..	52.6	30	0	100:0	Ice	*
	51.5	100	0	100:0	Ice	*
Average..	52.1	65	0	100:0		
40 to 45..	41.7	55	0	100:0	Ice	*
35 to 40..	37.7	100	0	100:0	Ice	*
30 to 35..	31.2	100	0	100:0	Ice	*
25 to 30..	29.5	75	0	100:0	Ice	*
	27.4	100	20	100:20	*	Dark
	26.9	100	0	100:0	Ice	*
Average..	27.9	91.7	6.6	100:7		
20 to 25..	24.8	100	100	100:100	*	Light
	22.9	100	0	100:0	Ice	*
	21.0	100	40	100:40	*	Dark and light
Average..	22.9	100	46.6	100:47		
15 to 20..	19.4	100	100	100:100	*	Medium dark
	19.3	100	80	100:80	*	Dark and light
	18.5	100	100	100:100	*	Medium dark
	17.7	100	100	100:100	*	Light
	17.6	100	100	100:100	*	Light
	16.4	100	100	100:100	*	Light
	16.0	100	100	100:100	*	Light
	15.7	100	100	100:100	*	Medium dark
Average..	17.6	100	97.5	100:98		
10 to 15..	14.8	100	100	100:100	*	Light
	14.7	100	100	100:100	*	Light
	14.1	100	100	100:100	*	Light
	13.8	100	100	100:100	*	Light
	13.7	100	100	100:100	*	Light
	13.2	100	100	100:100	*	Light
	13.0	100	100	100:100	*	Light
	11.7	100	100	100:100	*	Light
	10.8	100	100	100:100	*	Light
Average..	13.5	100	100	100:100		

*No observations made.

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TEMPERATURE RANGE 0° TO —5° F.

The notes on the corn subjected to a temperature of 0° to —5° F. are compiled in Table 9. It will be observed here that the injury resulting from exposure to this temperature occurred in those ears having a moisture content greater than 16 per cent. Below that, little or no injury resulted. The transition seems to have occurred between 20 and 18 per cent. Loss of viability or power of germination occurred here with a slightly smaller percentage of moisture than at the temperature of 8° to 4° F. Ice crystals were found in the kernels from a few ears in which the moisture content was as low as 20 per cent. However, little or no loss of viability occurred in ears containing 16 per cent or less of moisture.

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TABLE 9—*Effect of freezing temperatures on germination of corn differing in moisture content (1913 and 1914)*

Temperature range 0° to —7°F.

Moisture range	Moisture in grain	Germination			Ice observed in grain	Embryos dark or light
		Normal grain	Frozen grain	Ratio of normal to frozen		
Per cent	*Per cent*	*Per cent*	*Per cent*			
65 to 70..	67.8	100	0	100:0	Ice	Dark
60 to 65..	60.4	100	0	100:0	Ice	Dark
55 to 60..	59.6	100	0	100:0	Ice	Dark
	59.2	100	0	100:0	Ice	Dark
Average..	59.4	100	0	100:0		
50 to 55..	51.1	100	0	100:0	Ice	Dark
	50.3	100	0	100:0	Ice	Dark
Average..	50.7	100	0	100:0		
45 to 50..	49.7	100	0	100:0	Ice	Dark
	48.8	100	0	100:0	*	Dark
	48.5	100	0	100:0	Ice	Dark
	48.2	100	0	100:0	*	Dark
	46.8	100	0	100:0	Ice	Dark
	45.9	100	0	100:0	*	Dark
	45.6	100	0	100:0	Ice	Dark
	45.4	100	0	100:0	Ice	Dark
	45.3	100	0	100:0	*	Dark
	45.2	100	0	100:0	Ice	Dark
Average..	46.9	100	0	100:0		
	43.6	100	0	100:0	Ice	Dark
	43.3	100	0	100:0	*	Dark

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TABLE 9 *(Continued)—Effect of freezing temperatures on germination of corn differing in moisture content (1913 and 1914)*

Temperature range 0° to —5°F.

Moisture range	Moisture in grain	Germination			Ice observed in grain	Embryos dark or light
		Normal grain	Frozen grain	Ratio of normal to frozen		
Per cent	*Per cent*	*Per cent*	*Per cent*			
35 to 40	40.0	100	0	100:0	*	Dark
	40.0	100	0	100:0	*	Dark
	39.9	100	0	100:0	Ice	Dark
	39.8	100	0	100:0	*	Dark
	39.5	100	0	100:0	Ice	Dark
	39.5	100	0	100:0	Ice	Dark
	39.1	100	0	100:0	*	Dark
	38.8	100	0	100:0	*	Dark
	38.8	100	0	100:0	*	Dark
	38.4	100	0	100:0	Ice	Dark
	37.9	100	0	100:0	Ice	Dark
	37.7	100	0	100:0	Ice	Dark
	37.7	100	0	100:0	*	Dark
	36.8	100	0	100:0	Ice	Dark
	35.1	100	0	100:0	Ice	Dark
Average	38.6	100	0	100:0		
30 to 35	33.8	100	0	100:0	*	Dark
	33.1	100	0	100:0	Ice	Dark
	31.1	100	0	100:0	*	Dark
	30.4	80	0	100:0	Ice	Medium dark
	30.1	100	0	100:0	Ice	Dark
Average	31.7	96	0	100:0		
25 to 30	30.0	100	0	100:0	Ice	Dark
	28.7	100	0	100:0	*	Dark
	27.6	100	0	100:0	*	Dark
	26.7	100	0	100:0	*	Dark
	26.6	100	0	100:0	Ice	Dark
	25.9	100	0	100:0	*	Medium dark
	25.2	100	0	100:0	Ice	Light
	25.2	100	0	100:0	*	Dark
Average	27.0	100	0	100:0		

*No observations made.

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TABLE 9 *(Continued)—Effect of freezing temperatures on germination of corn differing in moisture content (1913 and 1914)*

Temperature range 0° to —5°F.

Moisture range	Moisture in grain	Germination			Ice observed in grain	Embryos dark or light
		Normal grain	Frozen grain	Ratio of normal to frozen		
Per cent	*Per cent*	*Per cent*	*Per cent*			
20 to 25	24.8	100	0	100:0	Ice	Dark
	24.5	100	0	100:0	None	Dark
	24.4	100	0	100:0	*	Dark
	22.3	100	0	100:0	None	Light
	21.5	100	0	100:0	*	Dark
	21.2	100	0	100:0	*	Medium dark
	20.5	100	0	100:0	Ice	Dark
Average	22.7	100	0	100:0		
15 to 20	20.0	100	20	100:20	None	Dark and light
	19.9	100	0	100:0	Ice	Dark and light
	18.9	100	60	100:60	*	Light
	18.4	100	20	100:20	*	Medium dark
	16.3	100	100	100:100	None	Light
	15.6	100	100	100:100	None	Light
	15.5	100	100	100:100	*	Light
	15.3	100	100	100:100	None	Light
Average	17.5	100	62.5	100:63		
10 to 15	14.8	100	100	100:100	*	Light
	14.4	100	80	100:80	*	Light
	14.3	100	100	100:100	*	Light
	13.6	100	100	100:100	None	Light
	13.0	100	100	100:100	None	Light
	11.9	100	100	100:100	None	Light
Average	13.7	100	96.6	100:97		

*No observations made.

SUMMARY OF GERMINATION TESTS UNDER CONTROLLED CONDITIONS

A summary of the average germinations of corn exposed to the different ranges of temperature, and containing various amounts of moisture, is given in Table 10. The data in this table are taken from the detail tables for the different temperature ranges. It will be noted from this table that (1) as the moisture content of the corn diminishes, the injury (with some

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TABLE 10—*Summary showing effect of various freezing temperatures on germination of corn differing in moisture content (1913-1914)*[1]

Per cent moisture in grain	Temperature ranges (degrees F.)				
	32 to 28	24 to 20	16 to 12	8 to 4	0 to —5
	Germination per cent	Germination per cent	Germination per cent	Germination per cent	Germination per cent
80 to 85	0	0	...	...	..
75 to 80	0	0	...	...	..
70 to 75	0	0	...	...	..
65 to 70	3	0	0	...	0
60 to 65	0	0	0	...	0
55 to 60	31	0	0	...	0
50 to 55	33	6	0	0	0
45 to 50	...	12	0	...	0
40 to 45	69	12	0	0	0
35 to 40	71	13	0	0	0
30 to 35	75	67	12	0	0
25 to 30	85	77	34	7	0
20 to 25	100	96	88	47	0
15 to 20	...	100	100	98	63
10 to 15	...	...	...	100	97

[1]This table is compiled from the averages found in Tables 5 to 9. The given temperatures were continued for a period of twenty-four hours.

irregularity) to the vitality of the kernel from exposure to any given temperature becomes less; (2) in the case of immature corn, freezing injury at a given moisture content increases as the temperature lowers; and (3) the vitality of corn with a moisture content ranging from 10 to 14 per cent is not injured by exposure to temperature of 0° to —5° F. for a period of 24 hours. For corn containing 20 to 25 per cent moisture, the germination percentages, when exposed to the temperature ranges of 32° to 28° F., 24° to 20° F., 16° to 12° F., 8° to 4° F., and 0° to —5° F., were respectively 100, 96, 88, 47, and 0 per cent.

EFFECT OF FREEZING ON DRY CORN

In 1911, freezing tests were made with corn which had been cured one month in a dry room, and also with corn cured three months. The grain at the time of freezing contained from 12 to 14 per cent moisture. The results of these tests are shown in Table 11. Practically no loss of vitality resulted in either case, even at the lowest temperature.

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TABLE 11—*Effect of freezing temperatures on the germination of corn which had been cured in a dry room before freezing (1911). Moisture range in grain 12 to 14 per cent.*

Length of drying period	Temperature range (degrees F.)	Per cent germination		Number of samples tested
		Normal grain	Frozen grain	
1 month	28 to 32	100	100	8
	20 to 24	100	100	8
	12 to 16	100	100	8
	4 to 8	100	97	8
3 months	28 to 32	100	100	8
	20 to 24	100	100	8
	12 to 16	100	100	8
	4 to 8	100	100	8

NATURAL RESISTANCE OF GREEN CORN TO COLD

It was thought desirable in connection with this work to determine as nearly as possible not only the degree of cold necessary to weaken or destroy the vitality of the corn kernel but also the length of time necessary for cold to operate before injury results. The latter tests were made as nearly under natural field conditions as possible, so far as the corn itself was concerned,—the ears being undisturbed in the husks, and placed in the freezing apparatus as soon as brought from the field. Five or six ears were frozen at a time. The plan was, to select ears of the four degrees of maturity used in previous tests, and subject them to a given range of temperature for varying periods of time. Again similar sets of ears were subjected for a given time to varying ranges of temperature. As soon as the ears were removed from the freezing chamber, moisture samples were taken and the ear husked and laid away to dry. Later, germination tests were made and notes taken regarding the color of the embryo. The data are compiled in Table 12. The germination tests tend to indicate that light freezing temperatures of short duration are not particularly injurious even to corn of high moisture content, while long exposure, 20-24 hours, to the same temperature may prove fatal. As the temperature is reduced, the duration of exposure necessary to injury becomes shorter. This is indicated in summary Table 13. The data for the 24 hour period in this table are calculated from Tables 5 to 9. While tests at this temperature are not strictly comparable with those of 1915 in that the husks were removed from

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TABLE 12—*Effect of exposure to ranges of freezing temperature for different periods of time on the germination of corn differing in moisture content. All ears were protected naturally by the husks (1915)*

Moisture range	Duration of exposure	Minimum temperature	Moisture in grain	Germination	Ice observed in grain	Embryos dark or light
Per cent	*Hours*	*Degrees F.*	*Per cent*	*Per cent*		
75 to 80	4	24	77.4	92	*	Light and dark
	6	32	76.4	100	*	Light
70 to 75	6	32	71.6	100	*	Light and dark
65 to 70	12	28	67.6	83	*	Dark
60 to 65	2	32	62.5	100	*	Light
	4	30	61.5	100	*	Light and dark
	4	28	60.7	100	*	Light
	12	28	64.4	93	*	Light and dark
55 to 60	4	30	59.7	100	*	Light and dark
	4	28	55.9	100	*	Light
	4	14	57.8	75	Ice	Light
	8	23	55.5	100	Ice in some kernels	Light
	8	18	58.8	50	Ice	Light and dark
	8	3	56.7	8	Ice	Dark
	10	14	58.4	19	Ice	Dark
	15	25	56.1	92	Ice in some kernels	Light and dark
50 to 55	2	32	54.5	100	*	Light
	4	24	50.5	100	*	Light and dark
	6	16	51.2	25	Ice	Light and dark
	8	23	52.5	100	*	Dark
	10	23	51.4	91	Ice in some kernels	Light
	10	14	53.2	67	Ice	Light
	10	3	52.7	0	Ice	Dark
	2	23	49.5	100	*	Light
	2	10	45.9	85	*	Light and dark
	4	14	45.6	75	Ice	Light and dark

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TABLE 12 *(Continued)—Effect of exposure to ranges of freezing temperature for different periods of time on the germination of corn differing in moisture content. All ears were protected naturally by the husks (1915)*

Moisture range	Duration of exposure	Minimum temperature	Moisture in grain	Germination	Ice observed in grain	Embryos dark or light
Per cent	*Hours*	*Degrees F.*	*Per cent*	*Per cent*		
40 to 45	2	27	43.5	100	*	Light and dark
	2	20	44.4	100	*	Light
	6	23	42.1	100	*	Light and dark
	6	7	42.2	42	Ice	Light and dark
	8	23	45.0	100	Ice in some kernels	Light
	8	18	43.0	100	Ice in some kernels	Light and dark
	8	3	44.2	0	Ice	Dark
	10	14	43.8	67	Ice	Light and dark
	12	21	42.1	100	Ice in some kernels	Light
	12	14	44.6	63	Ice in some kernels	Light and dark
	15	25	44.3	96	Ice in some kernels	Light
35 to 40	2	23	37.9	100	*	Light
	4	5	35.4	45	Ice	Light and dark
	6	23	36.2	100	*	Light
	6	16	38.1	50	Ice in some kernels	Light and dark
	6	7	39.9	50	Ice	Light and dark
	10	23	36.2	100	None	Light and dark
	12	21	39.2	83	None	Light and dark
	12	1	37.3	0	Ice	Light and dark
30 to 35	2	10	33.0	92	*	Light
	4	23	34.1	100	*	Light
	8	3	34.7	47	Ice	Light and dark
	10	23	34.5	100	None	Light
	10	3	34.6	8	Ice	Light and dark
	12	1	32.4	25	Ice	Light and dark
	32	25	33.6	100	None	Light
25 to 30	2	20	29.4	100	*	Light
	2	10	26.6	100	*	Light and dark
	4	5	28.0	92	Ice	Light
	12	21	26.4	100	None	Light
	12	1	27.8	42	Ice	Light and dark
20 to 25	2	20	24.4	100	*	Light
	4	14	24.3	100	None	Light
15 to ...	6	16	22.2	100	None	Light

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TABLE 13—*Summary showing effect of length of exposure and degree of cold on the vitality of corn varying in moisture content (1915)*

Moisture in grain	Duration	M nimum temperature 26°F.	Minimum temperature 18°F.	Minimum temperature 10°F.	Min'mum temperature 2°F.	Minimum temperature —5°F.
Per cent	*Hours*	*Germination Per cent*	*Germination Per cent*	*Germination Per cent*	*Germination Per cent*	*Germination Per cent*
70 to 80	2	...	...	...	...	..
	4	...	92	...	...	..
	6	100		...	...	..
	8	...	...	...	...	..
	10	...	...	...	...	..
	12	83	...	...	...	..
	15	...	...	...	...	..
	24	0	0	...	...	..
60 to 70	2	100	...	...	...	..
	4	100	...	...	...	..
	6	...	...	...	...	..
	8	...	...	...	...	..
	10	...	...	...	...	..
	12	88	...	...	...	..
	15	...	...	...	...	..
	24	2	0	0	...	0
50 to 60	2	100	...	...	...	..
	4	100	100	75	...	..
	6	...	...	25	...	..
	8	...	83	...	8	..
	10	...	91	43	0	..
	12	...	...	...	...	..
	15	...	92	...	...	..
	24	32	2	0	0	0
40 to 50	2	100	100	85	...	..
	4	...	...	75	...	..
	6	...	100	...	42	..
	8	...	94	...	0	..
	10	...	...	67	...	..
	12	...	100	63	...	..
	15	...	98	...	...	..
	24	69	12	0	0	0

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TABLE 13 *(Continued)—Summary showing effect of length of exposure and degree of cold on the vitality of corn varying in moisture content (1915)*

Moisture in grain	Duration	Minimum temperature 26°F.	Minimum temperature 18°F.	Minimum temperature 10°F.	Minimum temperature 2°F.	Minimum temperature —5°F.
Per cent	*Hours*	*Germination Per cent*	*Germination Per cent*	*Germination Per cent*	*Germination Per cent*	*Germination Per cent*
30 to 40	2	...	100	92	...	..
	4	...	100	...	45	..
	6	...	100	50	50	..
	8	...	...	...	47	..
	10	...	100	...	8	..
	12	...	83	...	...	13
	15	...	...	...	...	..
	24	72	40	7	0	0
20 to 30	2	...	100	100	...	..
	4	...	...	100	92	..
	6	...	...	100	...	..
	8	...	...	...	...	..
	10	...	...	...	...	..
	12	...	100	...	...	42
	15	...	...	...	...	..
	24	90	83	64	28	0
10 to 20	2	...	...	...	...	..
	4	...	...	...	100	..
	6	...	...	...	...	..
	8	...	100	...	...	..
	10	...	...	...	92	..
	12	...	...	...	...	..
	15	...	...	...	...	..
	24	...	100	100	99	77

this corn before being exposed to the freezing temperatures, and the minimum temperatures were not exactly the same, yet it was thought that owing to the length of the freezing period both the husked and the unhusked corn would be affected in practically the same way. This is the reason for including the data for the 24-hour period in this table.

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VITALITY OF CORN EXPOSED TO FREEZING TEMPERATURES IN THE FIELD

GENERAL SURVEY

As a sort of check on the work done under controlled conditions in the laboratory, a study was made of the vitality of corn exposed to fall and winter freezing in the field during the years 1913-1917. Moisture tests were made at the time the corn was gathered. When the corn was thoroly dry, germination tests were made and the color of the embryo was noted. A record is given of all freezing weather to which the corn was exposed prior to gathering.

Because of the differences in exposure and the repeated freezing and thawing, these data are not strictly comparable with the data obtained from the laboratory tests. However, these data substantiate the principles established under the controlled conditions.

Prior to these more detailed investigations, a general study of the condition of corn had been made in the fall of 1911 and 1912. In the fall of 1911 a severe frost occurred on November 11 and 12. At this time the temperature dropped so low, and corn contained so much moisture, that a very large per cent of the crop in Nebraska was frozen and its power of germination destroyed. The average corn crop contained at that date from 20 to 25 per cent of moisture, and much of it contained more than this amount. The temperature fell as low as 2° F. and remained at that low mark for four hours. (Tables 14 and 15.) Corn which ripened earlier and was drier, however, was not injured. This together with the other field studies and laboratory tests seems to indicate that corn which contains as low as 16 or 17 per cent of moisture is in no danger of losing its vitality from exposure to the ordinary autumn freezes.

The freezing which occurred in 1911 prior to November 13 is indicated in Table 14.

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TABLE 14—*Freezing temperatures during autumn 1911. Degrees F.*

Hour of day	Oct. 21	Oct. 23	Oct. 27	Oct. 28	Oct. 29	Oct. 31	Nov. 1	Nov. 2	Nov. 3	Nov. 4	Nov. 7	Nov. 10	Nov. 11	Nov. 12	Nov. 13
A. M.															
12-1	..	..	..	..	..	..	..	16	27	31	..	..	..	4	17
1-2	..	..	..	..	32	..	..	15	27	31	..	32	..	4	19
2-3	..	..	32	32	32	31	..	15	27	31	..	29	..	2	20
3-4	32	..	32	32	32	30	32	14	26	30	..	27	..	2	21
4-5	31	32	32	31	32	29	27	14	26	31	..	23	32	2	21
5-6	31	32	31	30	31	28	26	13	26	32	..	22	30	2	23
6-7	30	..	30	29	..	28	23	12	26	..	32	21	26	3	24
7-8	31	..	31	28	..	27	20	13	26	..	31	21	21	4	25
8-9	..	..	32	32	..	31	21	27	27	..	..	22	17	7	29
9-10	..	..	..	..	..	..	21	22	28	..	..	25	14	9	..
10-11	..	..	..	..	..	..	21	25	29	..	..	28	13	12	..
11-12	..	..	..	..	..	..	21	27	30	..	..	32	12	15	..
P. M.															
12-1	..	..	..	..	..	..	23	28	31	..	..	..	12	17	..
1-2	..	..	..	..	..	..	25	30	31	..	..	..	11	19	..
2-3	..	..	..	..	..	..	24	29	32	..	..	..	11	20	..
3-4	..	..	..	..	..	..	24	29	32	..	..	..	11	20	..
4-5	..	..	..	..	..	..	24	28	..	..	..	..	10	20	..
5-6	..	..	..	..	..	..	22	28	..	..	..	..	10	18	..
6-7	..	..	..	..	..	..	21	27	..	..	..	..	9	18	..
7-8	..	..	..	..	..	..	20	27	..	..	..	..	8	17	..
8-9	..	..	..	..	..	..	19	27	..	..	..	..	7	16	..
9-10	..	..	..	..	..	..	18	26	..	..	..	..	7	15	..
10-11	..	..	..	..	..	..	17	26	31	..	..	..	7	16	..
11-12	..	..	..	..	..	..	16	27	31	..	..	..	6	16	..

TABLE 15—*Duration with mean and minimum temperature of freezing periods during autumn 1911*[1]

Date	Hours in period	Mean temperature degrees F.	Minimum temperature degrees F.
Oct. 21	5	31.0	30
Oct. 23	2	32.0	32
Oct. 27	7	31.4	30
Oct. 28	7	30.6	28
Oct. 29	5	31.8	31
Oct. 30	7	29.1	27
Nov. 1-3	60	24.2	12
Nov. 3-4	8	31.0	30
Nov. 7	2	31.5	31
Nov. 10	11	25.6	21
Nov. 11-13	53	14.2	2

[1]Compiled from Table 14.

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The dates on which the first freezing temperatures recorded by the weather bureau, three miles distant, have occurred during the last seven years are as follows: 1911, October 21; 1912, October 22; 1913, October 20; 1914, October 27; 1915, October 8; 1916, September 29; 1917, October 8.

This shows October 15 to be the average date for the first freezing temperature recorded by the weather bureau, during this period, whereas the average date for the first killing frost was October 12. The freezing temperatures which occurred on the above dates were not low enough, however, to affect the vitality of the corn in any way, unless the corn should have been exceedingly immautre. Even this class of corn is rarely injured by the first freezing temperatures because of their short duration. (See Table 13.)

The approximate moisture content of the average corn crop in eastern Nebraska on October 15, 1911, was 22 per cent; in 1912, it was 20 per cent; in 1913, it was 17 per cent; in 1914, it was 15 per cent; in 1915, it was 35 per cent; in 1916, it was 18 per cent; and in 1917, it was 37 per cent. These figures are based on the moisture content of corn harvested from the general field plats of the Experiment Station. They represent, no doubt, very nearly the average maturity of corn in eastern Nebraska at the time when freezing temperatures are likely to occur. It will be seen that usually corn is too mature to be injured in vitality by the first freezing weather. Even in 1915 when the moisture content was large the first freezing did little or no damage to the life of the seed. (See Table 22.) Farther north and west in the State, however, the season is shorter and freezing comes earlier. The corn in these sections, therefore, should be correspondingly earlier in order to insure normal vitality in the seed. Heavier freezing during the late fall and winter is more likely to do serious damage to the germination of corn not fully matured.

FIELD SELECTION IN 1913

In the fall of 1913, corn samples of various degrees of dryness were selected from the field on October 30, after 9 days of considerable freezing weather, during which time 98 hours of freezing temperature prevailed, with a minimum of 15° F. The notes on viability and color of germ are given in Table 16. The freezing temperatures which occurred during the fall and to which the corn had been exposed are indicated in Table 17. Table 18 summarizes these temperatures, giving the duration and the mean and minimum temperature of each freezing period.

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TABLE 16—*Germinative ability of corn which varied in degree of maturity and which was exposed in the field to the freezing temperatures of autumn. The degree of maturity is indicated by the moisture content of the grain. Corn harvested October 30, 1913.*[1]

Moisture range	Moisture in grain	Germination	Embryos dark or light
Per cent	*Per cent*	*Per cent*	
35 to 40	39.7	0	Dark
	39.7	0	Dark
	39.4	0	Dark
	37.0	0	Dark
	36.9	20	Dark
	35.7	0	Dark
Average	38.1	3	
30 to 35	34.3	40	Light
	34.1	0	Dark
	33.5	20	Dark
	32.9	60	Light
	32.3	0	Dark
Average	33.4	24	
25 to 30	30.0	20	Medium dark
	29.8	0	Dark
	27.7	40	Light
	27.6	100	Light
	27.1	60	Dark and light
	26.7	80	Light
	26.4	0	Dark
Average	27.9	43	
20 to 25	24.4	100	Light
	23.9	80	Light
	23.2	80	Light
	22.7	100	Light
	22.3	100	Light
	21.2	100	Light
Average	23.0	93	
15 to 20	20.0	100	Light
	19.4	100	Light
	15.3	100	Light
	15.3	100	Light
Average	17.5	100	
10 to 15	14.2	100	Light
	14.1	100	Light
Average	14.2	100	

[1]See Tables 17 and 18 for freezing temperatures prior to October 30.

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TABLE 17—*Freezing temperatures during autumn, 1913. Degrees F.*

Hours of day	Oct. 19	Oct. 20	Oct. 21	Oct. 23	Oct. 26	Oct. 27	Oct. 28	Oct. 29	Oct. 30	Oct. 31	Nov. 1
A. M.											
12-1	..	26	28	..	..	28	..	21	23	25	..
1-2	..	25	26	32	..	26	..	21	22	24	32
2-3	..	24	25	32	..	25	..	21	21	23	32
3-4	..	23	24	..	..	24	..	21	20	23	32
4-5	..	23	23	..	..	23	..	19	19	22	32
5-6	..	25	23	..	..	22	..	18	19	22	32
6-7	..	27	22	..	..	24	31	15	18	22	32
7-8	..	29	24	..	32	21	30	15	18	23	..
8-9	..	32	26	..	32	30	28	17	21	25	..
9-10	..	..	28	..	..	..	27	20	24	32	..
10-11	..	..	31	..	..	..	26	23	28	..	..
11-12	..	..	..	..	..	..	26	26	..	..	..
P. M.											
12-1	..	..	..	..	..	..	26	28	..	..	..
1-2	..	..	..	..	..	..	27	31	..	..	..
2-3	..	..	..	..	..	..	28	..	..	..	..
3-4	..	..	..	..	..	..	28	..	..	..	..
4-5	..	..	..	..	..	..	26	32	..	..	..
5-6	..	..	..	..	..	..	25	30	..	..	..
6-7	..	..	..	..	..	..	24	28	..	..	..
7-8	30	..	..	..	..	..	23	27	..	..	..
8-9	28	..	..	..	..	..	23	26	31	..	..
9-10	27	..	..	..	..	..	23	26	29	..	..
10-11	29	..	..	..	32	..	23	25	27	..	..
11-12	28	29	..	..	29	..	22	23	25	..	..

TABLE 18—*Duration with mean and minimum temperatures of freezing periods during autumn of 1913* [1]

Date	Hours	Mean temperature	Minimum temperature

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The corn was grouped according to its moisture content, with a range of 5 per cent for each group. Corn ranging in moisture content from 10 to 15 per cent, and 15 to 20 per cent gave 100 per cent germination; 20 to 25 per cent moisture germinated 93 per cent; 25 to 30 per cent moisture germinated 43 per cent; 30 to 35 per cent moisture germinated 24 per cent; and 35 to 40 per cent moisture germinated 3 per cent.

These results conform very closely to those from the laboratory tests at a temperature range of 16° to 12° F., as may be seen by comparing with Table 7. In the laboratory, when subjected to a temperature of 16° to 12° F., corn containing 15 to 20, 20 to 25, 25 to 30, 30 to 35, and 35 to 40 per cent of water germinated respectively 100, 88, 34, 12, and 0 per cent, while the same grades of corn exposed in the field to a minimum temperature of 15° F. germinated respectively 100, 93, 43, 24, and 3 per cent.

FIELD SELECTION IN 1914

The results for corn selected from the field on November 22, 1914, after intermittent subjection to 111 hours freezing temperature with a minimum of 4° F. are given in Table 19. The freezing temperatures are given in detail in Table 20 and are summarized in Table 21, which gives the duration and the mean, and minimum temperatures for each freezing period. The respective mean germinations were 100, 67.5, 60, 55, and 30 per cent according to whether the moisture content of the grain ranged from 10 to 15, 15 to 20, 20 to 25, 25 to 30, or 30 to 35 per cent.

FIELD SELECTION IN 1915

A study was made in the fall of 1915 of the effect of early freezing temperatures on the vitality of corn when left in the field and exposed to the natural freezing weather of October and November. This year the corn was very immature at the time of the first killing frost and continued to retain a large per cent of water thruout the fall. Since there was also considerable variation in the maturity of individual ears, the

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TABLE 19—*Germinative ability of corn which varied in degree of maturity and which was exposed in the field to the freezing temperatures of autumn. The degree of maturity is indicated by the moisture content of the grain. Corn harvested November 22, 1914*[1]

Moisture range	Moisture in grain	Germination	Embryos dark or light
Per cent	*Per cent*	*Per cent*	
30 to 35	34.2	0	Dark
	31.3	60	Light
Average	32.8	30	
25 to 30	29.4	60	Dark
	28.7	80	Dark and light
	26.5	20	Dark
	26.3	60	Light
Average	27.7	55	
20 to 25	24.2	20	Dark
	24.0	20	Dark and light
	23.6	60	Light
	22.5	100	Light
	21.4	80	Dark
	21.2	60	Dark
	21.1	100	Light
	20.5	60	Dark and light
	20.2	40	Dark and light
Average	22.1	60	
15 to 20	19.9	40	Light
	19.9	60	Light
	19.6	20	Dark and light
	19.2	100	Light
	18.8	40	Dark and light
	17.8	100	Light
	17.6	100	Light
	16.8	80	Light
Average	18.7	67.5	
10 to 15	13.4	100	Light

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TABLE 20—*Freezing temperatures during autumn, 1914. Degrees F.*

Hours of day	Oct. 26	Oct. 27	Nov. 8	Nov. 13	Nov. 15	Nov. 16	Nov. 17	Nov. 18	Nov. 19	Nov. 20	Nov. 22
A. M.											
12-1	..	28	..	..	..	22	25	..	12	19	..
1-2	..	27	31	..	..	23	25	..	10	19	..
2-3	..	27	30	..	..	22	25	..	8	20	..
3-4	..	26	29	..	..	21	26	..	7	21	..
4-5	..	25	28	..	..	19	27	32	6	22	32
5-6	..	24	27	..	..	18	28	31	5	22	30
6-7	..	25	26	..	..	18	29	..	5	22	30
7-8	..	26	26	32	31	19	28	..	4	23	29
8-9	..	31	30	..	29	21	30	..	6	26	28
9-10	..	..	..	..	30	24	..	..	8	..	..
10-11	..	..	..	..	31	25	..	..	11	..	..
11-12	..	..	..	..	..	27	..	..	14	..	..
P. M.											
12-1	..	..	..	..	..	29	..	..	18	..	..
1-2	..	..	..	..	..	31	..	..	19	..	..
2-3	..	..	..	..	..	32	..	..	21	..	..
3-4	..	..	..	..	..	32	..	..	22	..	..
4-5	..	..	..	..	..	31	..	..	21	..	..
5-6	..	..	..	..	31	28	..	..	20	..	..
6-7	..	..	..	..	30	27	..	..	20	..	..
7-8	..	..	..	..	27	25	..	32	20	..	..
8-9	32	..	..	..	25	25	..	27	19	..	..
9-10	30	..	..	..	23	24	..	23	19	..	..
10-11	30	..	..	..	22	25	..	19	18	..	..
11-12	28	..	..	..	21	24	..	15	18	..	..

TABLE 21—*Duration with mean and minimum temperatures of freezing periods during autumn of 1914*[1]

Date	Hours in period	Mean temperature degrees F.	Minimum temperature degrees F.
Oct. 26-27	13	27.6	24
Nov. 8	8	28.4	26
Nov. 13	1	32.0	32
Nov. 15	4	30.2	29
Nov. 15, 16, 17	40	25.3	18
Nov. 18	2	31.5	31
Nov. 18, 19, 20	38	16.9	4
Nov. 22	5	29.8	28

[1]Compiled from Table 20.

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EFFECT OF EARLY FREEZING ON VARIETIES, 1915

On October 10, corn was gathered from twenty-seven different varieties and hybrids for moisture and germination tests. These varieties and hybrids represented many different stages of maturity at the time the frost came. Some were late varieties and were still very immature, while others were early and were comparatively dry. Intermediate stages were also represented. The moisture content of the grain and also of the cob at the time of harvest, together with the germination for each variety, is shown in Table 22. It will be noted from this table that the moisture content of the grain was still rather large for most varieties. The germination tests, however, are so nearly perfect for all, that it seems hardly possible to trace any injury back to the effect of the frost.

TABLE 22—*The germination of corn varying in degree of maturity and gathered on October 10, after the first killing frost in 1915. The degree of maturity is indicated by the per cent of moisture in the cob and in the grain*[1]

Variety name	Tasseling date	Per cent moisture		Per cent germination
		Cob	Grain	
Hogue's Yellow Dent	8–16	57.0	38.0	99
Boone Co. White	8–21	60.3	44.7	97
Boone Co. White x Hogue's	8–20	64.9	47.9	99
Nebraska White Prize	8–20	61.2	45.2	100
Nebraska White Prize x Hogue's	8–18	63.3	43.2	99
Bloody Butcher	8–19	55.0	39.9	99
Bloody Butcher x Hogue's	8–18	57.7	43.2	94
Calico	8–17	59.2	40.4	100
Calico x Hogue's	8–17	55.3	40.4	100
Reid's Yellow Dent	8–16	60.8	37.8	97
Reid's Yellow Dent x Hogue's	8–16	59.1	35.2	99
Iowa Silver Mine	8–15	51.1	33.7	99
Iowa Silver Mine x Hogue's	8–14	57.9	40.6	99
St. Charles White	8–13	53.8	31.6	100
St. Charles White x Hogue's	8–15	58.0	32.1	100
Pride of the North	8–13	41.1	23.8	100
Pride of the North x Hogue's	8–15	51.5	32.9	99
University No. 3	8–13	57.3	35.4	97
University No. 3 x Hogue's	8–14	56.6	36.5	99
White Cap	8–12	50.3	29.0	100
White Cap x Hogue's	8–14	52.5	33.6	97
Iowa Gold Mine	8–10	51.6	31.6	99
Iowa Gold Mine x Hogue's	8–12	55.5	35.4	97
Leaming	8– 9	57.1	33.8	99
Leaming x Hogue's	8–13	55.1	39.0	100
Minnesota No. 13	8– 4	40.9	18.3	100
Minnesota No. 13 x Hogue's	8– 8	47.4	26.6	100

[1]See Tables 24 and 25 for freezing temperatures prior to October 10

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EFFECTS OF MORE SEVERE FREEZING, 1915

On the morning of November 9, while the frost was still on, a number of ears were examined in the field for ice formation in the kernels. Moisture samples were taken from these ears and germination tests were made later. After rather severe freezing on November 14, and again on the 15th, observations were made, the same being taken as in the previous case. The data are compiled in Table 23. One interesting thing shown in this table is that ice formation in the kernel is not necessarily fatal to the vitality of the grain, also that the freezing of November 9 with a minimum of 30° F. and lasting five hours was not of sufficient duration to affect germination. From the data of November 15 it is interesting to note that even those ears on which the kernels were a solid frozen mass gave a fair per cent of germination. In these cases, however, the viability plainly was reduced.

TABLE 23—*Germinative ability of corn which was exposed in the field to the freezing temperatures of autumn, 1915*[1]

Extent of freezing in kernels	Moisture content	Germination
CORN GATHERED NOVEMBER 9	*Per cent*	*Per cent*
SECOND LIGHT FREEZE		
Not frozen, no ice found in kernels	36.0	100
Not frozen, no ice found in kernels	32.2	100
Not frozen, no ice found in kernels	31.3	100
Ice found in the base of some of the kernels	39.1	100
Ice found in the base of some of the kernels	30.7	100
Ice found in the base of some of the kernels	41.9	100
Ice found in the base of some of the kernels	41.8	100
Ice found in the base of some of the kernels	47.8	100
CORN GATHERED NOVEMBER 15		
FIRST SEVERE FREEZE		
Whole kernel frozen solid	53.3	67
Germ frozen solid, rest of kernel not frozen	43.4	67
Ice in base of kernel, germ and endosperm not frozen	26.3	75
Not frozen, no ice found in kernel	16.9	100

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TABLE 24—*Freezing temperatures during autumn of 1915. Degrees F.*

Hours of day	Oct. 8	Oct. 9	Nov. 9	Nov. 13	Nov. 14	Nov. 15	Nov. 16
A. M.							
12-1	..	32	..	..	26	24	..
1-2	..	30	32	..	25	24	..
2-3	..	30	31	..	24	24	..
3-4	..	..	31	..	23	23	..
4-5	..	..	30	..	22	23	..
5-6	..	..	30	..	22	23	31
6-7	32	..	..	..	22	24	29
7-8	..	..	..	..	21	27	27
8-9	..	..	..	..	26	30	28
9-10	..	..	..	..	30	..	..
10-11	..	..	..	..	..	..	..
11-12	..	..	..	..	..	..	..
P. M.							
12-1	..	..	..	..	..	..	..
1-2	..	..	..	..	..	..	..
2-3	..	..	..	..	..	..	..
3-4	..	..	..	..	..	..	..
4-5	..	..	..	31	..	..	..
5-6	..	..	..	30	..	..	..
6-7	..	..	..	30	31	..	..
7-8	..	..	..	29	30	..	..
8-9	..	..	..	28	28	..	..
9-10	..	..	..	28	27	..	..
10-11	..	..	..	28	26	..	..
11-12	..	..	..	28	25	..	..

TABLE 25—*Duration with mean and minimum temperatures of freezing periods during autumn, 1915*[1]

Date	Hours in period	Mean temperature degrees F.	Minimum temperature degrees F.
Oct. 8	1	32.0	32
Oct. 9	3	30.7	30
Nov. 9	5	30.8	30
Nov. 13-14	18	26.3	21
Nov. 14-15	15	25.9	23
Nov. 16	4	28.8	27

[1]Compiled from Table 24.

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In order to determine definitely the actual difference which may be found, moisture tests were made. For this purpose two ears were selected showing great variation in maturity of different kernels. The kernels from each ear were divided into groups according to maturity. The kernels from one ear were grouped as dry, and as damp. Only the extreme types were taken. The dry group represented the driest kernels on the ear, while the damp group represented the most immature kernels. Sprouted kernels were found on the other ear, and these were placed in a group by themselves. Moisture tests were then made for each group from each ear. The results are shown in Table 26. The table shows an average difference of 15.8 per cent between the damp and dry kernels. The sprouted kernels averaged 60.7 per cent moisture. The difference here indicated is sufficient to cause a great difference in susceptibility to cold, as indicated in previous tables, and no doubt explains in many cases why some kernels of an ear are killed by freezing while others are uninjured.

TABLE 26—*Variation in moisture content of kernels from the same ear of corn at the time of harvest. November 10, 1915*

Ear	Description of Kernels	Moisture content
		Per cent
1	Least mature	65.4
	Most mature	49.2
2	Least mature	63.5
	Most mature	48.2
	Sprouted	60.7

FIELD SELECTIONS IN 1917

Climatic conditions combined in such manner in 1917 that no season in this generation has been quite so unfavorable to the maturing and drying of the corn crop. The early growth was retarded by a cold, wet spring. Later it was again retarded by deficient moisture in July. Following that came an unusually cool August and September, which prolonged growth and delayed ripening. The first killing frost in the early morning of October 8, with a duration of nine hours and a minimum temperature of 24° F., (Table 30) was an unusually severe first frost. This was followed by three weeks of cold and freezing weather which not only retarded the drying of corn but continued to reduce its vitality.

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EFFECT OF FIRST KILLING FROST ON VARIETIES, 1917

The test with corn varieties and hybrids reported in Table 22 for 1915, was repeated in 1917. Types varying widely as to earliness and related moisture content were represented. An unusually large amount of moisture was present at the time of the first killing frost on October 8. Ten ears of each variety and hybrid were gathered the following day and tested for moisture and germination. The results are given in Table 27. The varieties and their hybrids represented many different stages of maturity at the time they were gathered for testing. The grain varied from 16 to 47 per cent moisture content, according to variety. The germination tests show very little injury from this first frost, even for the late maturing varieties.

TABLE 27—*Germination of corn varying in degree of maturity and gathered after the first killing frost on October 8, 1915. The degree of maturity is indicated by the per cent of moisture in the grain.*

Variety name	Tasseling date	Per cent moisture	Per cent germination
Hogue's Yellow Dent	8– 7	39	94
Boone Co. White	8–12	46	97
Boone Co. White x Hogue's	8–11	50	88
Nebraska White Prize	8–10	44	96
Nebraska White Prize x Hogue's	8– 8	42	99
Bloody Butcher	8–11	46	93
Bloody Butcher x Hogue's	8–10	47	94
Calico	8–10	34	94
Calico x Hogue's	8–10	41	95
Reid's Yellow Dent	8– 6	38	100
Reid's Yellow Dent x Hogue's	8– 7	44	99
Iowa Silver Mine	8– 7	26	100
Iowa Silver Mine x Hogue's	8– 7	44	92
St. Charles White	8– 5	37	94
St. Charles White x Hogue's	8– 6	38	96
Pride of the North	8– 2	29	95
Pride of the North x Hogue's	8– 5	37	97
University No. 3	8– 8	37	95
University No. 3 x Hogue's	8– 8	40	95
White Cap	8– 5	38	96
White Cap x Hogue's	8– 6	34	96
Iowa Gold Mine	8– 9	32	95
Iowa Gold Mine x Hogue's	8– 8	41	88
Leaming	8– 8	37	94
Leaming x Hogues	8– 7	44	94
Minnesota No. 13	8– 2	17	99
Minnesota No. 13 x Hogue's	8– 4	27	92

[1]For freezing temperatures see Table 30.

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DEGREES OF MATURITY SELECTED FROM FIELD AT DIFFERENT DATES IN FALL AND WINTER OF 1917

Five 10-ear samples of corn differing in maturity and moisture content were selected from a field of Hogue's Yellow Dent corn on October 8, 1917, following the first, but severe, freezing spell of the season. As nearly corresponding samples as possible were selected at four succeeding dates, namely on November 19, December 11, December 29, and January 15, for the purpose of observing the effects of additional degrees of freezing under natural field conditions. The field was neither the ripest nor the greenest at the Station, but was of medium maturity, and represented about an average condition for eastern Nebraska that season. The five selected samples of this seed ranged from mature seed down to the late dough stage of maturity.

Two additional samples were selected from other fields at each of the above dates and tested together with the above five samples. One was mature seed selected from a field of Hogue's Yellow Dent corn which had been cut and shocked late in September. The other was very immature seed selected in the milk stage from a field of late planting.

A description of the seven samples together with their moisture content and germination are given in Tables 28 and 29.

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inative ability of Hogue's Yellow Dent corn which was exposed in the field to arious amounts of freezing during the fall and winter of 1917

at time of first killing October 8	Proportion of total corn in field	Moisture Content		Germination			Estimated germination based on color of germ
		Cob	Grain	Perfect	Im-perfect	Total	
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
orn gathered October 8—First killing frost with minimum temperature 24°F.							
tured, ears solid	30[1]	50	30	98	0	98	100
d:							
tured, ears solid	7	56	35	98	0	98	100
bery, ears twist	15	58	39	94	3	97	100
grain medium soft	22	61	43	92	5	97	100
	25	61	47	92	1	93	100
ge	30	63	50	82	10	92	100
	..[1]	63	63	44	11	55	100
Corn gathered November 19—Prolonged freezing with minimum of 17°F.							
tured, ears solid	30	26	17	85	13	98	100
d:							
tured, ears solid	7	23	17	83	8	91	90
bery, ears twist	15	39	21	56	15	71	52
grain medium soft	22	45	26	34	7	41	21
	25	48	27	14	3	17	8
ge	30	50	34	10	4	14	10
	..	52	36	1	1	2	0

lots 1 and 7 were taken from a different field than the other samples.

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28 (Continued)—Germinative ability of Hogue's Yellow Dent corn which was exposed in the field to various amounts of freezing during the fall and winter of 1917

n of corn at time of first killing frost, October 8	Proportion of total corn in field	Moisture Content		Germination			Estimated germination based on color of germ
		Cob	Grain	Perfect	Imperfect	Total	
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Corn gathered December 11—Prolonged freezing with minimum of —16°F.							
rn:							
y well matured, ears solid	30	16	15	93	5	98	100
ling in field:							
y well matured, ears solid	7	17	16	87	4	91	88
ewhat rubbery, ears twist	15	25	18	79	6	85	87
rubbery, grain medium soft	22	38	23	20	5	25	6
n very soft	25	44	26	17	2	19	4
dough stage	30	47	28	10	1	11	0
stage	..	47	33	0	0	0	0
Corn gathered December 29—Prolonged freezing with minimum of —18°F.							
rn:							
y well matured, ears solid	30	18	16	87	11	98	100
ling in field:							
y well matured, ears solid	7	17	15	93	5	98	88
ewhat rubbery, ears twist	15	18	16	59	15	74	62
rubbery, grain medium soft	22	31	19	14	11	25	0
n very soft	25	33	21	5	7	12	0
dough stage	30	44	28	0	0	0	0
stage	..	45	29	0	0	0	0

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3 (Continued)—Germinative ability of Hogue's Yellow Dent corn which was exposed in the field to various amounts of freezing during the fall and winter of 1917

n of corn at time of first killing frost, October 8	Proportion of total corn in field	Moisture Content		Germination			Estimated germination based on color of germ
		Cob	Grain	Perfect	Im-perfect	Total	
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Corn gathered January 17—Prolonged freezing with minimum temperature of —21°F.							
ɔrn:							
y well matured, ears solid	30	15	14	86	10	96	88
ling in field:							
y well matured, ears solid	7	15	14	88	6	94	90
ewhat rubbery, ears twist	15	17	17	61	12	73	70
rubbery, grain medium soft	22	26	19	20	6	26	10
n very soft	25	36	22	6	1	7	0
dough stage	30	43	27	0	0	0	0
stage	..	42	28	0	0	0	0

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TABLE 29.—*Summary showing moisture content and germination of corn harvested at various dates during fall and winter of 1917*[1]

Condition of corn at time of first killing frost, October 8	Moisture in grain of corn gathered on					Per cent perfect germination of corn gathered on				
	Oct. 8	Nov. 19	Dec. 11	Dec. 29	Jan. 17	Oct. 8	Nov. 19	Dec. 11	Dec. 29	Jan. 17
Shocked corn:										
1. Fairly well matured, ears solid	30	17	15	16	14	98	85	93	87	86
Corn standing in field:										
2. Fairly well matured, ears solid	35	17	16	15	14	98	83	87	93	88
3. Somewhat rubbery, ears twist	39	21	18	16	17	94	56	79	59	61
4. Very rubbery, grain medium soft	43	26	23	19	19	92	34	20	14	20
5. Grain very soft	47	27	26	21	22	92	14	17	5	6
6. Late dough stage	50	34	28	28	27	82	10	10	0	0
7. Milk stage	63	36	33	29	28	44	1	0	0	0
Minimum temp. (degrees F.)	..	..	..	..	..	24	17	—16	—18	—21

[1]Compiled from Table 28. For a record of all freezing temperatures prior to each selection from the field, see Table 30.

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The freezing temperatures prevailing up to the time of the last selection—January 17, 1918—are indicated in Table 30.

TABLE 30—*Duration, mean temperature, and minimum temperature of freezing periods during autumn and early winter (1917-1918)*

Date	Hours in period	Mean temperature (degrees F.)	Minimum temperature (degrees F.)
Oct. 8	9	27.7	24
Oct. 10	1	32.0	32
Oct. 11-12	11	26.8	23
Oct. 12-13	8	27.9	25
Oct. 18-19	13	23.8	18
Oct. 20-21	5	31.2	31
Oct. 22-23	13	28.8	23
Oct. 24	2	32.0	32
Oct. 26	5	31.0	30
Oct. 27	6	31.0	30
Oct. 28-30	45	25.2	17
Oct. 30-31	12	26.7	24
Oct. 31-Nov. 1	12	27.8	26
Nov. 1-2	10	30.2	29
Nov. 4	5	30.2	29
Nov. 18-19	14	26.1	21
Nov. 23	10	28.1	24
Nov. 23-24	15	25.4	19
Nov. 24-25	17	30.2	28
Nov. 26	2	32.0	32
Nov. 26-27	5	30.6	30
Nov. 27-28	14	23.4	18
Nov. 29	3	32.0	32
Nov. 30	9	28.7	26
Nov. 30-Dec. 1	10	28.1	26
Dec. 1-2	10	28.6	27
Dec. 3	12	25.9	22
Dec. 3-4	14	20.1	22
Dec. 4-16	290	5.6	—16
Dec. 17	3	31.7	31
Dec. 18	5	30.6	30
Dec. 20-21	14	26.4	25
Dec. 21-22	14	27.0	20
Dec. 24-26	61	17.6	12
Dec. 26-Jan. 1	136	11.3	—18
Jan. 2-3	33	20.7	15
Jan. 3-4	16	29.1	25
Jan. 5-17	290	7.0	—23

At 9 o'clock A. M., on October 8, following the heavy frost earlier in the morning, a thermometer inserted into the center of the cob of corn ears hanging naturally in the field recorded a

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temperature of 31.5° F. Thus the freezing temperature of this first freeze penetrated thru the husks to the center of the ear. The grain on the more immature ears was considerably frozen. The selection of the various samples, as described in Table 28, was based entirely upon the external appearance and feel of the ear. At each successive selection the corn was noticeably drier. However, each sample in the later selections was chosen as nearly as possible to duplicate the corn in the corresponding sample in the first selection. No attention was given to the appearance of the germ in selecting each sample. However, the germs were later examined for color, and the probable germination was estimated, based upon the color of the germ. The data in Table 28 show that a fairly reliable estimate of viability may be made by an examination of the germ.

The data in Table 29 indicates that most of the freezing injury to seed corn in the field in 1917 occurred between October 8 and November 19, and that little injury occurred following this date. Altho much more severe freezing followed, the corn had dried out sufficiently to withstand it. In general, corn in the field which was sound on November 19, 1917, was also sound on January 15, 1918.

The vitality of grain containing more than 17 per cent of moisture on November 19 was so reduced by the temperatures which prevailed up to that date as to make it unreliable for seed purposes. On the other hand, the driest grade standing in the field, and that from the shocked corn, was not injured seriously, giving germination tests of 86, and 88 per cent perfect germination respectively, tho exposed to all the low temperatures prior to January 17. On this date, the field from which the various selections reported in Tables 28 and 29 were made tested 31 per cent germination, field-run.

CONDITION OF CORN IN CRIBS ON JANUARY 26, 1918

The condition of corn in three Lancaster County corncribs was investigated on January 26, 1918. These cribs contained Reid's Yellow Dent, Chase's White Dent and St. Charles' White Dent corn. The crib-run tests of these cribs were 45, 39, and 26 per cent germination respectively. The corresponding tests of seed selected because of the sound outward appearance of the ears were 86, 89, and 90 per cent germination. It was estimated that to select 1 bushel of these grades of corn from each of these cribs required 80, 100, and 140 minutes respectively for one man. All these tests could doubtless have been improved by further testing and elimination of the inferior ears. Seven,

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six, and three per cent of the corn in the respective cribs were selected for the above grades.

THE DANGER LINE OF FREEZING INJURY

An approximate safety zone free from freezing injury may be established for seed corn differing in moisture content. The combinations of low temperature and freezing duration which seed corn will withstand as indicated in Fig. 13, are constructed from the various tests reported in this bulletin and should be regarded as approximate rather than absolute. They set forth the probable duration of a given low temperature which corn of given moisture content will withstand without injury. A slight lowering of the temperature or a longer duration of the exposure may initiate a reduction in the per cent germination but will not prove entirely fatal. Greater fatality will result as the adverse factors are extended.

It will be noted that in general an extension of the time of exposure is comparatively as dangerous as is the lowering of the temperature, until the moisture content in the grain is reduced to nearly 20 per cent where it manifests a decidedly greater resistance to the duration of exposure. A still more marked proportional resistance to the duration of exposure is shown by corn containing as low as 17 per cent moisture. When air-dry, containing 14 per cent or less of moisture, corn will endure any natural low winter temperature for any length of time.

OCCURRENCE OF AUTUMN FROSTS IN NEBRASKA

The dates for the first autumn frosts occur with great irregularity in Nebraska. As extremes for Lincoln, Nebr., during the last 21 years, the first killing frost occurred in 1902 on September 12, and in 1914 on October 27. As seen in Table 31 the dates of the first killing frost and the first dates with a recorded freezing temperature of 32° F. or lower do not always coincide. This is due to the fact that the Weather Bureau temperatures are obtained at a considerable distance above the ground, where the temperature does not always drop quite so low as it does nearer the surface. The average date of the first killing frost at Lincoln during the past 21 years has been October 12.

Table 31 gives the duration of the first freezing temperature together with the mean and minimum temperatures of the period, during the last 21 years at Lincoln.

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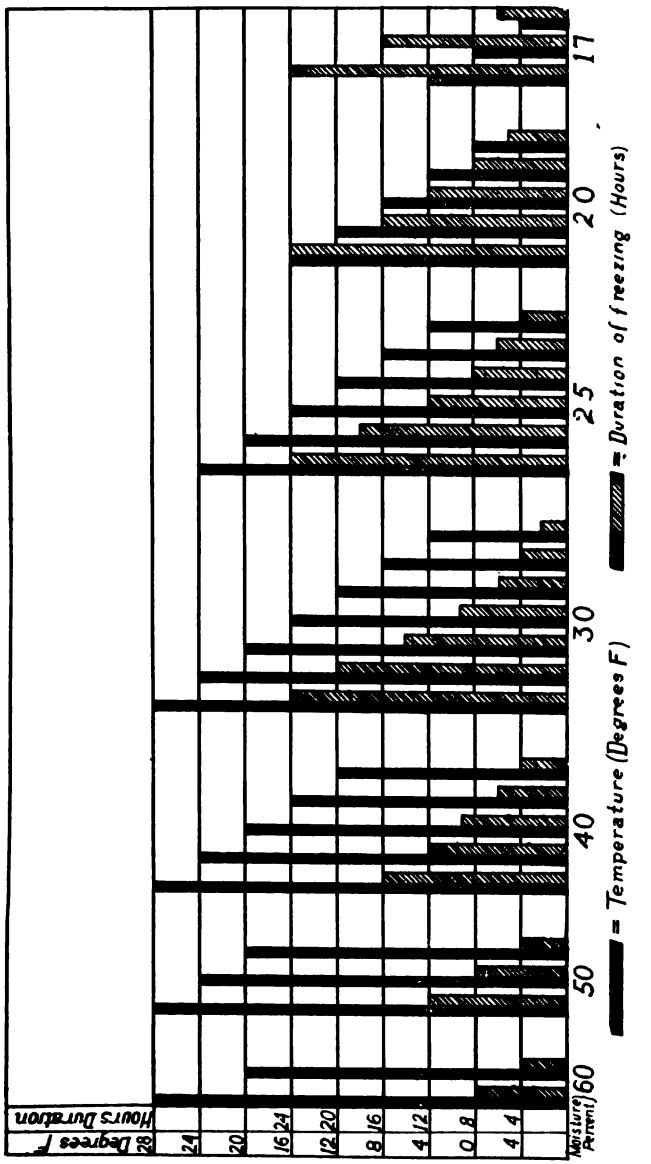

Fig. 13—The points of danger to seed corn of various moisture contents from freezing injury at given temperatures and stated hours of continuous exposure. A material adverse extension of freezing temperature, duration of freezing, or moisture content is likely to reduce the per cent germination. Air-dry corn containing less than 14 per cent moisture will withstand any natural low winter temperature for any length of time.

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TABLE 31—*Dates of the first killing frost and of the first freezing temperatures at Lincoln, Nebr., during 21 years, 1897 to 1917*

Year	Date of first killing frost	First date with temperature of 32°F. or below	Duration of freezing temperature	Mean temperature during period	Minimum temperature during period
			(*Hours*)	(*Degrees F.*)	(*Degrees F.*)
1897	Oct. 29	Nov. 2	10	30.0	29
1898	Oct. 6	Oct. 6	3	31.7	31
1899	Sept. 29	Sept. 29	7	29.3	27
1900	Oct. 17	Nov. 8	14	26.3	21
1901	Sept. 18	Sept. 18	3	31.7	31
1902	Sept. 12	Oct. 28	6	30.5	29
1903	Oct. 27	Oct. 27	3	31.7	31
1904	Oct. 25	Oct. 25	3	31.7	31
1905	Oct. 20	Oct. 20	7	31.0	30
1906	Oct. 10	Oct. 10	10	29.5	26
1907	Oct. 12	Oct. 12	4	31.0	30
1908	Oct. 11	Nov. 2	5	31.0	30
1909	Oct. 12	Oct. 12	16	28.0	21
1910	Oct. 22	Oct. 27	12	29.0	26
1911	Oct. 20	Nov. 1, 2 and 3	58	23.6	12
1912	Sept. 30	Oct. 22	6	31.3	30
1913	Oct. 20	Oct. 20	14	27.0	23
1914	Oct. 27	Oct. 27	13	28.0	24
1915	Oct. 9	Oct. 9	3	31.3	30
1916	Sept. 29	Sept. 29	5	31.0	30
1917	Oct. 8	Oct. 8	9	27.7	24
Av'ge	Oct. 12	Oct. 18	10	29.6	27

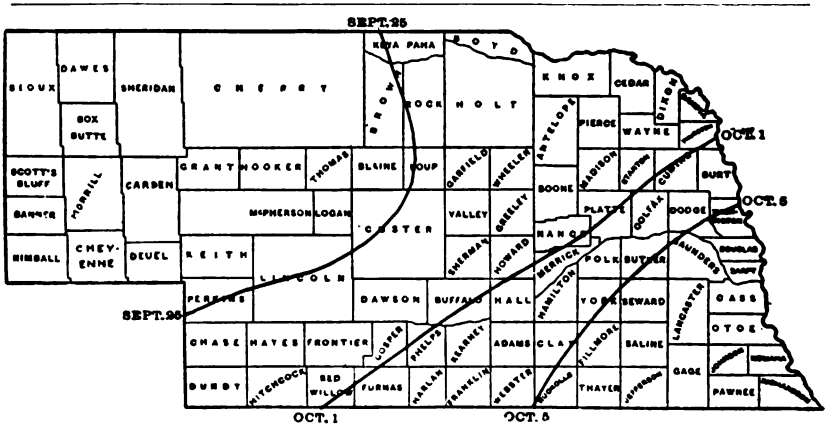

Fig. 14—Average date of the first killing frost in autumn. By G. A. Loveland

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This variation in time of freezing weather together with a great seasonal variation in time of corn maturity has a marked bearing in different years upon the condition of corn for seed when left standing in the field.

The average dates of the first killing frost in the field in the fall for various parts of Nebraska are given in Figure 14.

FREEZING INJURY INEVITABLE IN OCCASIONAL YEARS

Experience has taught that the best adapted, highest producing corn for any locality in Nebraska, or in the greater part of the Corn Belt, does not mature and dry sufficiently in all seasons to escape freezing injury when left exposed to low temperatures either in the field or in the crib. It would not be practicable in most of the Corn Belt to grow corn sufficiently early to escape damage from freezing every year, because such corn would be too small and early to give best results. The best adapted and most productive types appear to be those which utilize practically the entire growing season of the average year. In the majority of years, such types should ripen fully before the first killing frost, altho in occasional years both the yield and the quality may be reduced by autumn frosts.

Seasonal variation in the time of maturity of a given corn in a given locality may be illustrated by the relative maturity of Hogue's Yellow Dent corn at the Experiment Station in 1914 and 1917. This is a standard well-adapted type for conditions prevailing at the Experiment Station. In 1914 the grain of this corn contained only 14 per cent moisture on October 1, while it contained 38 per cent on October 1, 1917. It was well matured on September 6, 1914, whereas it was not so mature a month later in 1917. In this vicinity the normal date of ripening for this variety is September 20, while the mean date of the first killing frost is October 11. According to this, corn which is unsurpassed in average production at the Experiment Station ripens, as an average, about 3 weeks before the mean date of the first killing frost.

This seasonal variation makes possible in many years the growing of late maturing types of corn in localities where they normally are not adapted. But the character of the season and the date of the first killing frost cannot be foretold at planting time. Therefore, unadapted, late maturing types which do not reach their full development before the average date of the first killing frost should not be grown. They require for their full development the exceptional seasons in which the first killing frost comes very late. In too great a proportion of the

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seasons they fail to mature, and too frequently produce an inferior quality of corn together with a low yield of grain per acre.

SELECTION FOR EARLINESS

Wherever varieties of too late maturity are being grown, this may be overcome in several ways: (1) Securing seed of some earlier type. This may originate in the same locality or be of some previously tried variety obtained from a distance. Before a new corn is extensively substituted for an old one, definite knowledge should be had regarding its local adaptation. (2) Field selection of seed from the earlier maturing plants before autumn frosts, while such difference is readily discernible. (3) Selection of the drier and more mature ears later in the season. To a considerable extent, such ears are more mature because of inherent relative earliness. Corn may be made to average a week or ten days earlier in maturity in a very few years by such selection. It is probable that most of the corn grown in Nebraska could be made a week earlier without reducing the average yield, and the quality would be improved.

A rather arbitrary ideal of deep rough grain is held by many corn growers. This quality is usually associated with late maturity and also high shelling percentage. A mistaken conception prevails that high shelling percentage means high acre yield. To the contrary, corn with a rather medium depth kernel yields fully as much grain per acre, ripens somewhat earlier, is often of much better quality and frequently possesses stronger viability.

ALTERNATIVES IN SEED SELECTION

(1) Special, early field selection, before any likelihood of frost, may be practiced regularly each year. When such corn is stored and cured in a dry, well-ventilated place, good germination without further trouble is reasonably certain. This procedure, systematically insures sound seed corn. An essential requirement in this practice is to avoid immediate contact between the different ears so long as they are not well dried out. Thus mould and decay will be prevented. By going thru the field with a sack hung over the shoulder, or other simple device, the best developed and most matured ears may be readily gathered. Seed selected in the stiff dough stage is sufficintly mature to produce strong, vigorous plants. However, more mature seed is more ersily preserved.

(2) Selecting seed late in September or early in October, while husking corn in the regular way for early hog feed, is a safe

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and convenient manner of obtaining sound seed corn. Precaution should be taken to insure rapid drying and avoidance of mould. This procedure usually requires some husking before the bulk of the corn is sufficiently dry for general husking. The necessary seed for the average farm may usually be selected from several loads of this early husked corn. If this plan is systematically followed, a supply of sound corn may be fairly certain year after year.

(3) Selecting seed at the time of general husking is the most common of all methods. Either a box is attached to the side of the wagon into which the seed ears are thrown while husking, or else the seed ears are selected from the wagon while unloading. This method, and particularly the practice of picking the seed ears in the field while husking, has many commendable features in years of early maturity when a large percentage of the ears will possess strong germination even when left exposed in the field to severe freezing weather. In other years, such as 1911, 1915, and 1917, there may be such a small portion of viable ears after subjection to freezing weather, that much annoyance and difficulty is experienced in selecting them.

If necessary to select seed ears from a field where freezing injury has been severe, the rather slender, hard, solid, smooth ears with relatively shallow grains (Fig. 15) will be found most certain to give satisfactory germination. For those who do not favor this type of ear, it may be said that it is likely to yield fully as much grain to the acre as the larger, rougher types, even in years when both give equally good germination. Severe freezing destroys the viability of immature seed.

This is a factor in the natural adaptation of the crop. It tends to eliminate the later strains, while the earlier ones survive. By selecting the ears, therefore, which have withstood severe freezing in the field, more consistent earliness is developed.

(4) Corncrib selection may be practiced in an emergency as a last resort. If provision for a seed supply by other methods has been overlooked, well matured and sound seed ears may in most years be selected from the crib during the winter or spring. Such home grown seed is to be recommended in preference to imported seed whose adaptability is not definitely known.

(5) *Old Seed.* In order to insure against emergencies, it is a desirable practice to select sufficient seed in years when corn matures well for two years' planting. It seldom happens that two successive bad years occur, and by this practice much uneasiness and annoyance may be avoided in bad years. One-year-

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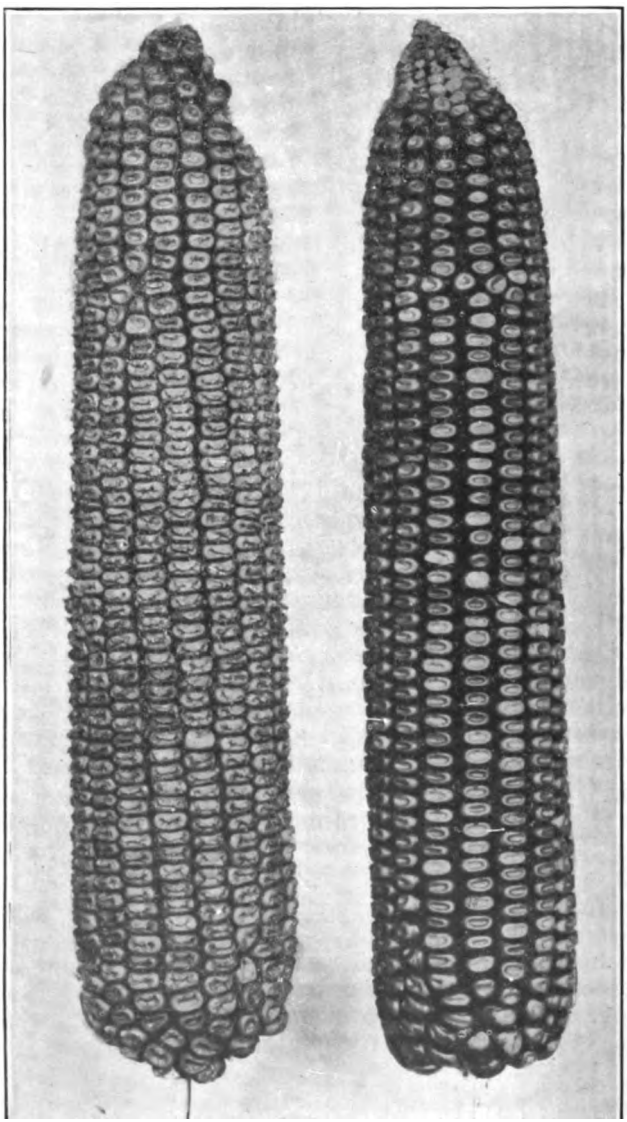

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old seed corn is entirely satisfactory if it has been well preserved.

COMBINATION OF METHODS FOR SELECTING SEED

For many farm operations, the procedure may be variable from year to year according to the seasonal conditions, or the individual farmer's fancy or convenience. This holds true in regard to the time and manner of selecting the seed corn supply. The conditions are very exceptional in which a satisfactory seed supply with apparently equal productivity cannot be selected by any one of the first three methods just described. The relative convenience and practicability of the methods may vary from year to year. In years when corn is backward, it is good practice to select seed from corn husked early, before heavy and continued freezes are to be expected. In years of early maturity, when corn is well dried out, it may be quite as well to pick the seed ears at the time of regular husking. Whether special early selection is practised in such years may be left entirely to the convenience of the farmer. However, in years when corn is late in maturing, early selection and preservation of seed corn may avoid the great annoyance of sorting over a large quantity of corn for the small percentage of sound ears that will give satisfactory germination. Early selection is probably of greater importance in the northwestern half, than in the southeastern half of the State.

ASCERTAINING VIABILITY

After the seed ears are thoroly cured, a general germination test may be made of a composite sample of kernels taken scatteringly from each of several hundred ears at the rate of about six kernels per ear. If less than about 90 per cent perfect germination is obtained, a more severe elimination of unsound ears should be made. Discarding all ears with discolored germs and the making of an individual ear germination test are rather effective methods. The making of such tests is generally under-

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Fig. 16—A final germination test should be made to definitely determine what percentage of the seed will grow. The corn planter may then be adjusted for an average drop of the desired number of kernels

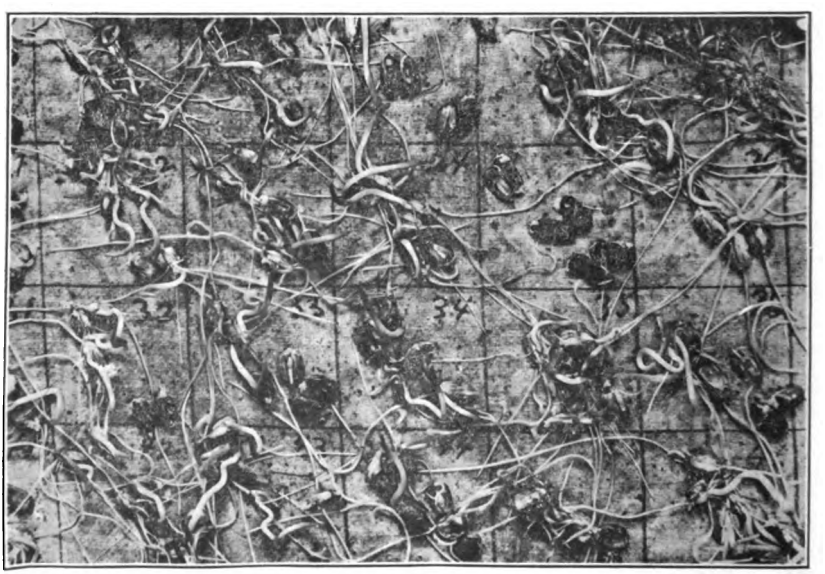

Fig. 17—The individual ear germination test shows definitely which are the unsound ears

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are obtained. Where less mature corn has been subjected to severe freezing, as high as 10 or 15 per cent may germinate imperfectly. Such seed may have either the plumule or the primary root killed, while the other end of the sprout may develop normally. If the plumule has been killed a viable root can never grow a new plumule. But if the primary root only is dead, the secondary roots may, under favorable germination conditions, develop at the base of the plumule and a normal plant result. Such imperfect sprouts may be seen in Figure 20.

Germination tests are often reported as so many strong, weak, or dead kernels. It would probably be quite as well to report perfect and imperfect germination and dead kernels. Since proper development of imperfect germs is doubtful, a classification into perfect and dead seed should suffice. Perfect kernels reported as weak are often relatively backward merely because of inherent slower germination or because of ununiform, unfavorable germinating conditions which act as sources of experimental error in testing.

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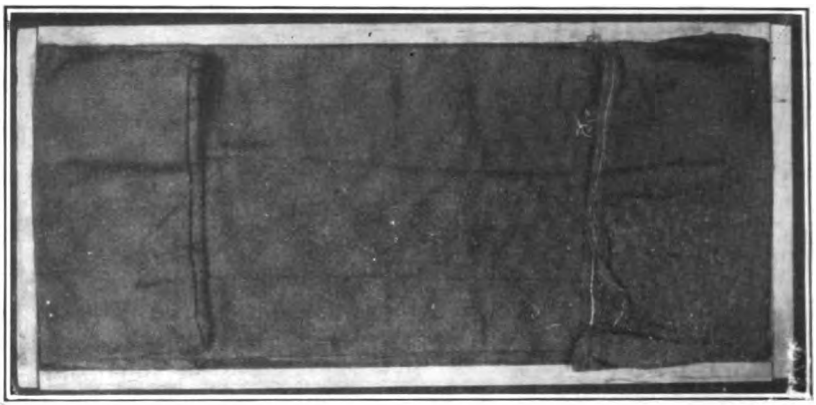

Fig. 18—Germination box filled with sawdust and covered with burlap to retain moisture

Fig. 19—The germination box shown in Figure 18, uncovered. Note the much more vigorous growth at the ends of the box where the burlap was folded back and greater pressure exerted by the box standing on top. The germinative ability of the corn at the center actually equalled that at the ends. This illustrates possible experimental error in testing for germination

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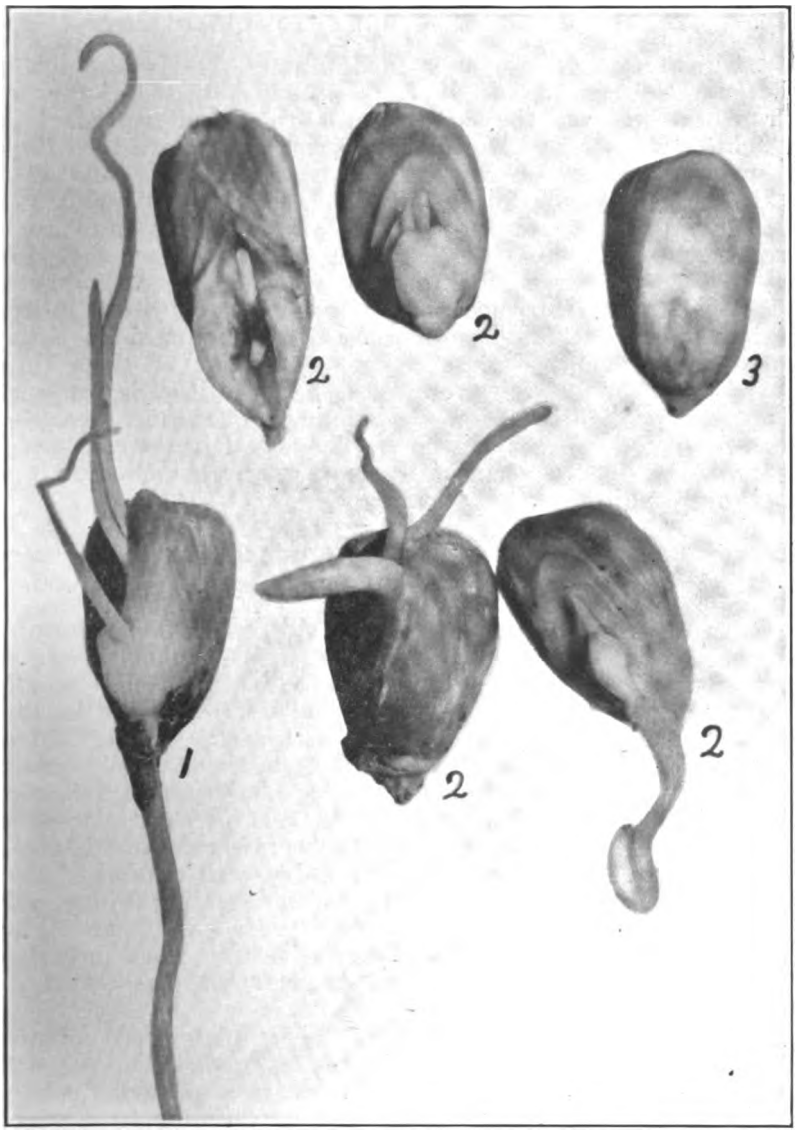

Fig. 20—Kernels showing various degrees of relative germinative ability. (1) Perfect germination; (2) imperfect germination; (3) dead kernels

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RELATIVE CORN YIELDS FOR THE STATE OF NEBRASKA IN YEARS FOLLOWING SEVERE SEED CORN INJURY

The average yield of corn for the State of Nebraska during the last 28 years, 1890 to 1917, as estimated by the Bureau of Crop Statistics and the State Board of Agriculture, has been 24.9 bushels per acre. During this period, there have been three years of serious seed corn injury, namely 1896, 1911, and 1915. The acre corn yields for the State in the years following this seed corn injury (years in which the affected seed was planted) were respectively 30.0, 27.1, and 32.6 bushels. Since the yield has been above normal each year in which it was necessary to plant seed selected from corn undergoing severe winter injury, it is evident that the farmers meet the situation in a fairly satisfactory manner. The average superiority of these three years above the 28 year average has been 5.0 bushels per acre. Therefore predictions of low yields following years of severe seed corn injury do not seem justified. The actual increase in yields is probably due to accidentally more favorable climatic and moisture conditions.

EFFECT OF TIME OF SELECTION AND PRESERVATION OF SEED CORN UPON YIELD

An experiment was begun in the fall of 1914 to determine the effect of the time of harvesting seed corn upon its yielding power provided care is taken in selection to obtain equally high germination. A comparative yield test was made in 1915 of September, November, and March selections from a field of Nebraska White Prize corn. This is a standard variety grown at the Experiment Station and adapted to southeastern Nebraska. A similar test was made in 1916 and 1917 of seed selected in September, October, November, December, February, and March. The seed was carefully preserved in a dry, well-ventilated place after being harvested. After danger from freezing injury, only seed ears which showed a bright clear germ were taken. Ears with discolored germs were discarded because they promised

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row of each plat for the yield test. This arrangement permitted a direct comparison of the inherent yielding capacity of the different lots. The results follow in Table 32.

TABLE 32—*Relative yields of seed corn selected at various dates during the fall and winter (1915-1917)*

Date of seed selection[1]	Duplications each year	Yield per acre				
		1915	1916	1917	Average 1916 and 1917	Three year average
		Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*
September	4	66.6	36.1	38.3	37.2	47.0
October	4	....	36.9	38.3	37.6	....
November	4	65.9	37.3	41.6	39.4	48.3
December	4	....	39.3	42.4	40.8	....
February	4	....	44.3	41.7	43.0	....
March	4	64.7	42.1	42.6	42.3	49.8
Check[2]	4	66.3	40.3	41.1	40.7	49.2

[1]The seed was harvested about the 15th of each month.

[2]The check seed was harvested from the same field while husking in November.

As an average for the three years 1915-1917, seed corn harvested by special selection from the field in September, November, and March, and given good care after selection, yielded respectively 48.2, 49.6, and 51.2 bushels per acre, while seed saved from the same field during the regular process of husking in November yielded 50.6 bushels per acre. We may conclude from these data that corn harvested early and given special care in preservation will not outyield seed which has been exposed to the cold of winter without special care, provided both are selected for high germinative qualities. Seed which has received no special early selection and preservation may be expected to yield as well as specially cared for seed, provided equally satisfactory stands are obtained. No claim is made, however, that seed selected late in winter will necessarily germinate as dependably as will that gathered earlier.

RELATIVE YIELDS OF DIFFERENT EAR TYPES

During the four years 1914 to 1917, four ear types of Nebraska White Prize corn have been compared in yield with the original unselected corn from which the types were selected

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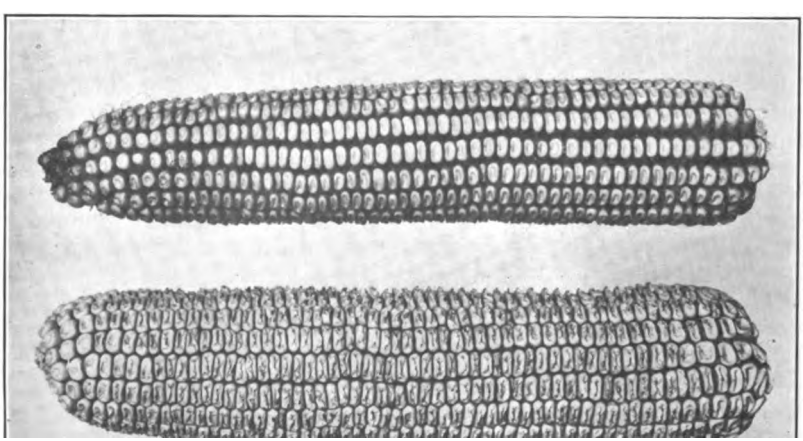
each year. This variety has been grown at the Experimental Station many years. The method of testing was the same as that described on page 84. Basing the yields upon equal numbers of plants grown under uniform conditions enabled a fairly reliable test of the relative inherent yielding qualities. The results are given in Table 33.

TABLE 33—*Yield per acre from different ear types of Nebraska White Prize corn (1914-1917)*

Type of ear	1914	1915	1916	1917	Average
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*
Original	48.7	64.8	65.5	53.5	58.1
Large rough	30.0	65.3	64.4	45.9	51.4
Short rough	44.4	68.9	65.1	49.9	57.1
Short smooth	45.0	72.6	60.1	49.2	56.7
Long slender smooth	48.7	66.4	65.2	54.9	58.8
Number of duplications	6	8	14	7	



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As an average for the four years, the long, slender, smooth type yielded 58.8 bushels per acre, which is 0.7 bushel more than the original corn, 7.4 bushels more than the large rough ears, 1.7 bushels more than the short rough ears, and 2.1 bushels more than the short, smooth ears. One may conclude that this long, slender, smooth sype possesses highly satisfactory yielding qualities, which, coupled with its superior germinative ability, makes it a very suitable type to grow. This type of ear is gaining greater popularity among corn men of the State, altho the old prejudice for deep rough ears with a high shelling percentage has been rather persistent.

EFFECT OF UNUNIFORM STAND ON YIELD

An investigation was made in 1915 and 1916 to determine the effect of varied distribution of plants upon the yield of corn. The number of plants per acre was the same in all cases, but the number of plants in adjacent hills differed. The purpose was twofold: (1) To learn the effect of variation in stand caused by mechanical variation in dropping by corn planters, when corn with perfect germination is planted. (2) To learn what result might be expected from planting corn, only part of which will grow, but for which the rate of planting has been calculated to seed the desired number of sound kernels per acre. The tests were made in duplicate 5-row blocks and equal numbers of each type of hill were harvested within each plat.

The methods of distribution compared were:

(1) All hills with uniformly 3 plants.

(2) Alternating hills with 2 and 4 plants.

(3) Alternating hills with 1, 3, and 5 plants.

(4) Alternating hills with 1, 2, 3, 4, and 5 plants. The results are given in Table 34. The average yield for the three

TABLE 34—*Effect of varied distribution of plants in planting compared with uniform distribution (1915 and 1916)*

Plants per hill	Yield per acre		
	1915	1916	Average
	Bushels	*Bushels*	*Bushels*

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varied distributions was 73.0 bushels compared with 74.3 bushels for the uniform planting rate of 3 plants per hill. A uniform stand of 3 plants per hill yielded 1.8 per cent more than the mean for the various distributions. Variations in stand due to the planter, or to the presence of dead seed in corn testing as low as 75 per cent, is less marked than the variations in the above special plantings.

The data in Table 34 are substantiated by a very similar experiment conducted by Montgomery in 1907 and 1908, the results of which are given in Table 35. The average yield of the varied distributions in this test was 2.1 per cent lower than a uniform distribution of three kernels.

TABLE 35—*Effect of varied distribution of seed in planting compared with uniform distribution (1907 and 1908)**

Grains planted per hill	Yield per acre		
	1907	1908	Average
	Bushels	*Bushels*	*Bushels*
Uniformly 3 grains	71.2	58.9	65.5
Alternating 2 and 4 grains	70.4	56.9	63.6
Alternating 1, 3 and 5 grains	70.7	60.1	65.4
Alternating 1 and 5 grains	64.5	60.6	62.6
Average for varied distribution	68.5	59.2	63.9

*Data in Table 35 taken from Nebraska Agricultural Experiment Station Bulletin 112, by E. G. Montgomery.

EFFECT OF IMPERFECT HILLS IN CHECKED CORN

The data in Tables 36 and 37 show how the crop adjusts itself for missing plants in an otherwise uniform stand. During the two years, 1914 and 1917, a rather large number of corn hills containing either 1, 2, 3 or no corn plants were scattered systematically thruout a field of checked corn otherwise containing 3 plants per hill. By harvesting the hills separately, the effect of hills containing 1, 2, or no plants upon hills with the normal number of 3 plants could be determined. Also the relative yields of hills containing 1, 2, or 3 plants when surrounded uniformly by 3-plant hills could be determined.

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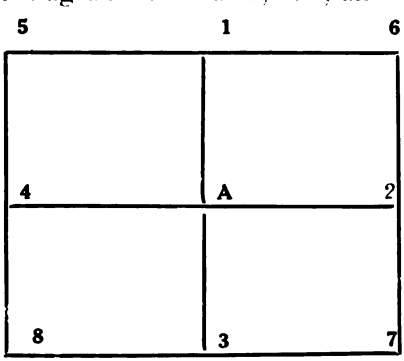
TABLE 36—*Relative yields of one, two, or three-plant corn hills when uniformly surrounded by three-plant hills. Nebraska White Prize corn (1914 and 1917)*

Number of plants in hills surrounded by uniform 3-plant hills	Total number hills averaged	Number of ears per 100 plants	Average grain yield per hill	
			Actual	Relative
			Pounds	
Hills with 3 plants	598	89	1.073	100
Hills with 2 plants	120	99	0.883	82
Hills with 1 plant	80	141	0.656	61

TABLE 37—*Relative yields of three-plant corn hills when adjacent to hills with various numbers of plants. Average for 1914 and 1917*

Three-plant hills surrounded by 3-plant hills except as indicated below	Total number hills averaged	Number of plants per hill	Number of ears per 100 plants	Average grain yield per hill	
				Actual	Relative
				Pounds	
Surrounded by hills with 3 plants	598	3	89	1.075	100
Adjacent to 1 hill with 2 plants	360	3	91	1.098	102
Adjacent to 1 hill with one plant	302	3	94	1.151	107
Adjacent to 1 blank hill	366	3	94	1.224	114

As an average for the two years, the two-plant hills yielded 18 per cent less than a three-plant hill, but each of four adjacent three-plant hills yielded 2 per cent more, due to the one missing plant. By adjacent hills, in this discussion, is meant the 4 surrounding hills in rows at right angles to each other and designated in the diagram below as 1, 2, 3, and 4.



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A one-plant hill yielded 39 per cent less than a three-plant hill, but on account of the two missing plants the yield of each of the four adjacent three-plant hills was increased 7 per cent thus recovering nearly three-fourths of the loss.

A no-plant hill yielded nothing, but each adjacent three-plant hill yielded 14 per cent more due to the three missing plants.

To sum up.—50 per cent of the yield lost in a hill with one missing plant was recovered in the four nearest adjacent hills; 72 per cent of what was lost in a hill with two missing plants was recovered in the four nearest hills; 56 per cent of what was lost in a hill with no plants was recovered in the four neareset adjacent hills.

While our experimental data show the effect of incomplete hills upon only the 4 nearest adjacent hills located at right angles, it is quite likely that the recovery extends at least to and possibly beyond the 4 nearest diagonal hills also indicated in the diagram at 5, 6, 7, and 8.

The fact that the yield is not greatly reduced by an un-uniform distribution of the plants (within reasonable limits) may be explained by the large feeding area of the roots of a corn plant. A corn hill is not limited to its own 3 feet 8 inches of land, but may laterally draw considerably beyond its adjacent neighboring hills for water and plant food material. Since these materials are usually limiting factors, a relatively greater abundance made available by one or more missing plants goes to increase the yields of other plants.

If a hill with one or two missing plants was partly surrounded by hills containing only a partial stand, it would not be reduced in yield to the same degree as when fully surrounded by 3-plant hills, because the competition would not be so large.

PROBABLE DISTRIBUTION OF PLANTS WHEN SEED OF LOW GERMINATION IS PLANTED

Every farmer has in mind some rather definite spacing of plants in the field which he regards as an optimum planting rate for his locality in the average year. Various experiments have indicated that there may be some variation in the planting rate without a material effect upon the yield.

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TABLE 38—*Showing chance distribution of plants when seed germinating 75, 65, and 50 per cent is planted in hills 44 inches apart*

Where corn germinates 75 per cent and 4 kernels are dropped per hill

Seed dropped per hill	Per cent such hills	Total number such hills per acre
4 sound	31.588	1,024
3 sound, 1 dead	42.258	1,370
2 sound, 2 dead	21.105	684
1 sound, 3 dead	4.664	151
4 dead	0.385	12
Total	100.000	3,241

Where corn germinates 65 per cent and 4 kernels are dropped per hill

Seed dropped per hill	Per cent such hills	Total number such hills per acre
4 sound	17.845	578
3 sound, 1 dead	38.455	1,246
2 sound, 2 dead	31.059	1,007
1 sound, 3 dead	11.144	361
4 dead	1.499	49
Total	100.000	3,241

Where corn germinates 50 per cent and 5 kernels are dropped per hill

Seed dropped per hill	Per cent such hills	Total number such hills per acre
5 sound	3.122	101
4 sound, 1 dead	15.622	506
3 sound, 2 dead	31.256	1,013
2 sound, 3 dead	31.256	1,013
1 sound, 4 dead	15.622	506
5 dead	3.122	101
Total	100.000	3,240

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below 85 an allowance should be made for the dead seed in the rate of planting.

By using partially unsound seed, a uniform stand cannot be obtained. But it has been shown that absolute uniformity is not necessary for maximum yields. An application of the law of chance (Table 38) shows how the sound kernels will be distributed when seed testing 75 per cent, 65 per cent, and 50 per cent is used with an approximate adjustment in the planting rate to compensate for the reduced germination.

The chance combinations of sound and dead seed per hill in Table 38, are calculated from the following formula:

The probability of dropping p sound kernels and q dead kernels from a composite sample containing m sound kernels and n dead kernels is:

$$\frac{m'}{(m-p)'} \quad \frac{(m+n-p-q)'}{(m+n)'} \quad \frac{n'}{(n-q)'} \quad \frac{(p+q)'}{p'\,q'}$$ where

$m' = m\,(m-1)\,(m-2)\,(m-3)\ldots\ldots 3,\ 2,\ 1$ = product of all intergers from 1 to m.

Acknowledgment is made to Prof. Carl Engberg, for supplying this formula.

For purpose of illustration, it will be assumed that approximately the rate of three sound kernels per hill is desired. The hills are spaced 44 inches apart. An acre contains 3,241 such hills.

DISTRIBUTION OF SOUND KERNELS WHEN SEED TESTS 75 PER CENT

If the corn tests 75 per cent and a stand of 3 plants per hill is desired, then 4 kernels should be planted per hill. The average hill will contain three sound and one dead kernel, but they will not be uniformly distributed. On the other hand, 31.6, 42.3, 21.1, 4.6, and 0.4 per cent of the hills will contain 4, 3, 2, 1, and no plants respectively. In an acre with 3,241 hills there will be 1,024 hills with 4 plants, 1,370 hills with 3 plants, 684 hills with 2 plants, 151 hills with 1 plant, and 12 hills without plants.

Results almost identical with the above calculation were obtained in an actual test with 1,500 hills, each of which contained 4 kernels taken at random. In this test 31.3, 41.6, 22.7, 4.1 and 0.13 per cent of the hills contained respectively 4, 3, 2, 1, and no plants as compared with 31.6, 42.3, 21.1, 4.6, and 0.4 per cent for chance calculations. For purposes of this study, the dead kernels were white and the sound kernels were yellow, which per-

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l distribution of sound kernels in hills when four kernels were taken at random for each seed germinating 75 per cent

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mitted correct separation. Figure 21 shows how these hills arranged themselves by chance in 25 rows of 60 hills each.

It is understood that this and the two following examples are illustrative and would be varied somewhat in farm practice for the reason that a planter cannot be set to always drop a uniform number of kernels per hill.

DISTRIBUTION OF SOUND KERNELS WHEN SEED TESTS 65 PER CENT

If corn testing 65 per cent germination is planted at the rate of 4 kernels per hill, then 17.8, 38.5, 31.1, 11.1, and 1 5 per cent of the hills respectively will have 4, 3, 2, 1, and no plants. An acre containing 3,241 hills will have 578 hills with 4 plants, 1,246 hills with 3 plants, 1,007 hills with 2 plants, 361 hills with 1 plant, and 49 hills with no plants. The no-plant and one-plant hills are likely to be distributed among the others in such manner that little reduced yield per acre need be expected.

By planting seed with a viability of 65 per cent at the rate of 4 per hill, 87 per cent as many plants per acre should be expected as when 75 per cent viable seed is planted at the same rate.

DISTRIBUTION OF SOUND KERNELS WHEN SEED TESTS 50 PER CENT

If corn is planted 5 kernels per hill, only half of which will grow, an acre will contain 101 hills with 5 plants, 506 hills with 4 plants, 1,013 hills with 3 plants, 1,013 hills with 2 plants, 506 hills with 1 plant, and 101 hills with no plants. The average rate per hill for such planting is 2½ sound kernels. The yield to be expected from such a distribution of plants should be fairly satisfactory. However, there seems little need for planting corn with so low a test.

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Research Bulletin 17 June, 1920

The Immunizing Value of Commercial Vaccines and Bacterins Against Hemorrhagic Septicemia

L. VAN ES AND H. M. MARTIN

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THE VALUE OF COMMERCIAL VACCINES AND BACTERINS AGAINST FOWL CHOLERA

By

L. VAN ES AND H. M. MARTIN

A great prevalence of the disease known as fowl cholera has naturally stimulated an interest in possible means of prevention and especially in those which may bring about a more or less lasting immunity. Attempts at immunizing against this disease date back to the very beginning of the era of modern bacteriology and immunology, and there is no doubt that many investigators succeeded in causing immunity in chickens by one method or other. Apparently, however, it has not yet been possible thru any of those methods to gain a solid footing and general dependability. Vaccines which were favorably reported by some failed utterly in the hands of others, so that on the whole no substantial advantage has been gained.

Vaccines and bacterins are nevertheless constantly urged on poultry owners confronted with disease and the Experiment Station is frequently called upon to give an opinion on their value or to recommend any special preparation.

In order to comply with those demands in an intelligent and impartial manner, we have thought it wise to make some experiments with the various preparations offered by the pharmaceutical trade in the hope that this may enable us to recommend all or any preparation for the relief of our poultry raisers.

A search through the advertising pages of veterinary journals showed that in all six manufacturers offered vaccines and bacterins against fowl cholera for sale and claimed for them immunizing powers sufficient to warrant the expenditure of money on the part of poultry producers.

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From those various manufacturers we purchased a quantity of their products, treated a given number of fowls with them and then tested the immunity of the latter by means of inoculations with fowl cholera organisms secured from field outbreaks and cultivated in our laboratory.

We hereby submit the details of those experiments in the following tables.

SAMPLE NO. 148.

This preparation was sold to us as "Hemorrhagic Septicemia Vaccine (Avian)." The details of the tests of this material are given in Table I.

TABLE I

Chicken No.	Fowl cholera vaccine No. 148 2/3 Quantity 1 c.c.	One loopful culture B. bipolaris avisepticus 2/11 Strain 38 B.	Dates of deaths	Remarks
1.....	—	X	2/12	All chickens were very sick the day after the virus injection.
2.....	—	X	2/14	
3.....	X	X	2/14	
4.....	X	X	2/13	
5.....	X	X	....	Very sick. Recovered
6.....	X	X	2/23	
7.....	X	X	2/17	
8.....	X	X	2/13	
9.....	X	X	....	Very sick. Recovered
10.....	X	X	2/15	
11.....	X	X	....	Very sick. Recovered

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18. A specimen of "Hemorrhagic Septicemia Combined Bacterin (Avian)." of the test are contained in Table II.

TABLE II

ections in No. 618 2/12	Injections of virus No. 623 2/21	Injections of virus No. 637 4/8	Dates of deaths	Remarks
½ c.c.	X	—	3/1	Lame and sick on 2/24
½ c.c.	X	X	—	Became sick after first virus. Recovered, sickened again after second virus injection. Destroyed 4/12. Very sick.
½ c.c.	X	—	3/4	Very sick on 2/24
½ c.c.	X	—	3/2	Sick on 2/24
½ c.c.	X	—	2/28	Very sick on 2/24
½ c.c.	X	—	2/23	
½ c.c.	X	—	3/13	Very sick on 2/24
½ c.c.	X	—	2/24	
½ c.c.	X	—	—	This subject became very sick 4/29 and remained so until it was destroyed 4/12.
½ c.c.	X	—	3/1	Very sick on 2/24
2 c.c.	X	—	2/26	Very sick on 2/24
2 c.c.	X	X	—	Sick on 2/24 and was still very sick when second dose of virus was given. Killed 2/12.
2 c.c.	X	X	—	Sick on 2/24. Had not quite recovered when second virus injection was made. Killed 4/12. May have recovered.
2 c.c.	X	—	2/27	Sick on 2/24
2 c.c.	X	—	2/26	Very sick on 2/24
2 c.c.	X	—	3/14	Sick on 2/24
2 c.c.	X	—	2/29	Sick and lame on 2/24
2 c.c.	X	—	2/29	Very sick 2/24
2 c.c.	X	—	3/2	Sick and lame 2/24
2 c.c.	X	—	3/30	2/24. The autopsy showed large necrotic foci in region of sternum which contained many bipolar organisms.
—	X	—	2/26	Virus control
—	X	—	2/26	Virus control
—	X	—	2/23	Virus control
—	X	—	2/23	Virus control

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Belonging to this same series are the six fowls of Table III which fifteen days after e last regular bacterin dose received 10 c.c. of the same substance. This was done in der to learn if any anaphylaxis may occur and also because we wished to learn whether not protection against actual disease may be secured through the use of extra large ses. What happened to those chickens, when called upon to prove their immunity may found in Table III.

TABLE III

en	Injection bacterin No. 618			Injection B. bipolaris No. 637 3/8	Injection B. bipolaris No. 637 4/8	Dates of deaths	Remarks
	½ c.c.	½ c.c.	10 c.c.				
	2/7	2/12	2/27				
...	X	X	X	X	X	—	The 10 c.c. bacterin dose caused a transitory weakness. The fowl was sick 3/15 but recovered. Sec. virus injection no results.
...	X	X	X	X	—	3/16	Transitory weakness after last bacterin injection. Sick on 3/21.
...	X	X	X	X	—	3/14	Ditto. Sick 3/10.
...	X	X	X	X	—	3/12	Ditto. Sick and lame 3/10.
...	X	X	X	X	—	3/16	Ditto. Sick on 3/10.
...	X	X	X	X	X		Sick and lame on 3/10. When killed still sick on 4/12. Weakness after 10 c.c. bacterin injection.

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. 630.

paration labelled: "Avian Hemorrhagic Septicemia Bacterin." (Table IV.)

TABLE IV

Injections: ns bacterin No. 630		Injections: B. bipolaris No. 637		Dates of deaths	Remarks
2/24	2/27	3/8	4/8		
2 c.c.	2 c.c.	X	—	3/10	
2 c.c.	2 c.c.	X	—	3/10	
2 c.c.	2 c.c.	X	—	3/9	
2 c.c.	2 c.c.	X	X	4/12	Chicken was still sick when killed.
2 c.c.	2 c.c.	X	X	3/10	
2 c.c.	2 c.c.	X	X	4/12	Sick 3/11. Was moribund when killed.
2 c.c.	2 c.c.	X	X	4/12	Sick 3/11. In very poor condition when killed.
2 c.c.	2 c.c.	X	—	3/9	
2 c.c.	2 c.c.	X	—	3/10	
2 c.c.	2 c.c.	X	—	3/9	
2 c.c.	2 c.c.	X	—	3/14	Sick on 3/11.
2 c.c.	2 c.c.	X	—	3/12	Sick on 3/11.
2 c.c.	2 c.c.	X	—	3/19	
2 c.c.	2 c.c.	X	—	3/10	
2 c.c.	2 c.c.	X	—	3/9	
—	—	X	—	3/10	
—	—	X	—	3/9	
—	—	X	—	3/11	
—	—	X	—	3/9	
—	—	X	—	3/13	

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SAMPLE No. 676.

Sold under the label of: "Avisepticus Bacterin." (Table V.)

TABLE V

Chicken No.	Injection bacterin No. 676 2 c.c.			Injection B. bipolaris No. 673 1 loopful	Dates of deaths	Remarks
	3/12	3/15	3/18	3/30		
1.....	X	X	X	X	3/21	
2.....	X	X	X	X	4/3	Sick on 3/31
3.....	X	X	X	X	4/3	Sick on 3/31
4.....	X	X	X	X	4/2	Sick on 3/31
5.....	X	X	X	X	4/1	
6.....	X	X	X	X	4/4	Sick on 3/31
7.....	X	X	X	X	4/12	Killed. Chronic cholera. Sick on 3/31
8.....	X	X	X	X	4/12	Killed — in good health had not been sick
9.....	X	X	X	X	4/12	Sick on 3/31. Very sick when killed
10.....	X	X	X	X	4/6	Sick on 3/31
11.....	X	X	X	X	4/3	Sick on 3/31
12.....	X	X	X	X	4/1	Sick on 3/31
13.....	X	X	X	X	4/5	Sick on 3/31
14.....	X	X	X	X	4/8	Sick on 3/31
15.....	X	X	X	X	4/12	Killed. Sick on 3/31. Developed chronic cholera
16.....	—	—	—	X	4/1	Control
17.....	—	—	—	X	4/1	Control
18.....	—	—	—	X	3/31	Control
19.....	—	—	—	X	4/1	Control
20.....	—	—	—	X	3/31	Control
21.....	—	—	—	X	4/1	Control
22.....	—	—	—	X	4/1	Control
23.....	—	—	—	X	3/31	Control
24.....	—	—	X	X	3/31	Control
25.....	—	—	—	X	4/3	Control. Sick on 3/31
26.....	—	—	—	X	4/1	Control
27.....	—	—	—	X	3/31	Control

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SAMPLE No. 682.

A preparation labelled: "Hemorrhagic Septicemia Vaccine (for fowls)." (Table VI.)

TABLE VI

Chicken No.	Injections vaccine No. 682 2 c.c. 3/17	3/20	3/23	Injections B. bipolaris No. 637 1 loopful 3/30	Dates of deaths	Remarks
1	—	—	—	X	4/1	Control
2	—	—	—	X	4/8	Control. Sick on 3/31
3	X	X	X	X	4/7	Sick on 3/31
4	X	X	X	X	4/4	Sick on 3/31
5	X	X	X	X	4/3	Sick on 3/31
6	X	X	X	X	3/31	
7	X	X	X	X	3/31	
8	X	X	X	X	3/31	
9	X	X	X	X	4/1	
10	X	X	X	..	3/31	
11	X	X	X	X	4/1	
12	X	X	X	X	4/3	Sick on 3/31
13	X	X	X	X	3/31	
14	X	X	X	X	3/31	
15	X	X	X	X	4/11	Sick on 3/31
16	X	X	X	X	4/9	Sick on 3/31
17	X	X	X	X	3/31	
18	X	X	X	X	4/8	Sick on 3/31
19	—	—	—	X	4/2	Sick on 3/31. Control
20	—	—	—	X	4/1	Control
21	—	—	—	X	3/31	Control
22	—	—	—	X	3/31	Control
23	—	—	—	X	3/31	Control
24	—	—	—	X	3/31	Control
25	—	—	—	X	4/10	Sick on 3/31. Control
26	—	—	—	X	4/12	Sick on 3/31. Control Recovering when killed
27	—	—	—	X	4/1	Control
28	—	—	—	X	3/31	Control
29	—	—	—	X	3/31	Control

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SAMPLE No. 741.

A product sold as: "Fowl Cholera Bacterin." (Table VII.)

TABLE VII

Chicken No.	Injections bacterin No. 741. c.c.			Injections B. bipolaris No. 637 1 loopful	Dates of deaths	Remarks
	4/19	4/22	4/25	5/7		
1.....	1	1	1	1	5/18	Sick 5/10. Very sick when killed
2.....	1	1	1	1/10	5/12	Sick 5/10
3.....	1	1	1	1	5/8	
4.....	1	1	1	1	5/18	Very sick when killed
5.....	1	1	1	1/10	5/14	Sick on 5/10
6.....	—	1	1	1	5/12	
7.....	—	1	1	1	5/11	
8.....	—	1	1	1	5/13	
9.....	—	1	1	1/10	5/8	
10.....	—	1	1	1	5/13	
11.....	—	—	1	1	5/10	
12.....	—	—	1	1/10	5/8	
13.....	—	—	2	1	5/18	Sick 5/10. Very sick when killed
14.....	—	—	1	1	5/18	Sick 5/10. Very sick when killed
15.....	—	—	1	1	5/9	
16.....	—	—	1	1	5/18	Sick 5/10. Apparently recovered when killed Necrosis at point of inoculation. Many organisms present.
17.....	—	—	—	1/10	5/9	Control
18.....	—	—	—	1/10	5/9	Control
19.....	—	—	—	1/10	5/9	Control
20.....	—	—	—	1/10	5/9	Control
21.....	—	—	—	1	5/11	Control
22.....	—	—	—	1	5/9	Control
23.....	—	—	—	1	5/9	Control
24.....	—	—	—	1	5/11	Control
25.....	—	—	—	1	5/8	Control

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Summarizing the results of the preceding series, we find as follows: (Table VIII.)

TABLE VIII

Number of chickens of which immunity was tested	Number of bacterin or vaccine injections	Results	
		Chickens sick or dead	Chickens immune
18	1	18	0
25	2	25	0
57	3	56	1
100	..	99	1

It is evident from the above that no reliance can be placed on the vaccines and bacterins against fowl cholera, which we are able to find on the market and subject to definite tests. We have no doubt as to the possibility of artificial immunity as an aid to the control of fowl cholera, but as yet we will have to get along with the more non specific means of prevention, even if those are far from a universal efficiency.

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RESEARCH BULLETIN NO. 19

THE UNIVERSITY OF NEBRASKA
BULLETIN
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AGRICULTURAL EXPERIMENT STATION
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THE REGIONAL ADAPTATION OF CORN IN NEBRASKA

By T. A. KIESSELBACH AND F. D. KEIM

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SUMMARY

Adaptation in corn is looked upon as the fortuitous or chance modification or acquisition of hereditary characters or qualities thru the favorable reaction of the crop to its environment. This may occur thru, (1) mutation from an individual, thus producing a new character; (2) Mendelian recombination of unit characters resulting in new forms; and (3) segregation of the more suitable types present in a mixed population. Survival of the fittest is the active selective principle.

Nebraska's climate is very diversified and affords a splendid opportunity for studying the regional adaptation of corn. Soil differences are not nearly so great a factor in this adaptation as is climate.

As extremes in climatic conditions, western Nebraska compared with eastern Nebraska normally has a six-degree F. lower temperature during the corn growing season. The frost-free period is fifty days shorter, and the precipitation one-half as great. The growing season of northern Nebraska is four degrees F. cooler than of southern Nebraska, and the frost-free period is about twenty days shorter. The precipitation from north to south is rather similar. Much of the country south of the Platte River is subject to occasional hot winds which are far less common north of this river. No statistics are to be had regarding the evaporation rates for various parts of the State, but experience indicates that the evaporation rate decreases from south to north. This increases the effectiveness of the rainfall.

With an approach from the relatively favorable conditions of eastern Nebraska to the combined short season, low temperature, and low precipitation of western Nebraska, the native corn types assume a more and more dwarfish growth habit. The stalks become shorter and bear the ear closer to the ground. The total leaf area per plant decreases thru a reduction in number, length, and width of the leaves. The ratio of leaf area to dry plant substance and the proportion of grain to stover remain fairly constant. The ears become shorter, smaller in circumference, fewer rowed and frequently are scrubby in appearance. The shelling percentage lowers, and the kernels become shorter and more flinty, as well as slightly lighter in weight.

The leaves, being the seat of transpiration and food synthesis, might be expected to reflect structural adaptation to adverse conditions, if such adaptation occurs. Therefore, extensive studies of leaf structure have been made. The leaf and epidermal thicknesses of native types are fairly constant thruout the State. There is a tendency in the less favored regions for the stomata to be somewhat smaller and greater in number per unit leaf

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area. This stomatal character is associated with a rather corresponding reduction in size of epidermal cell, all of which may be ascribed to a more dwarfish development. The number of vascular bundles per unit cross-section of leaf is fairly constant.

While some of the vegetative characters, such as total leaf area and plant weight, may reduce as much as 300 per cent, no important histological leaf characters exhibit more than 15 per cent deviation in the case of native types growing in the most adverse as compared with the most favored parts of the State.

Practically speaking, adaptation with corn consists in a morphological rather than in a histological reaction.

As a concrete example of the foregoing adaptive reactions, the 1915 difference between home-grown native Richardson County and Kimball County corn types may be cited. These two localities represent the extremes of corn growing conditions within the State. Comparing the measurements of Richardson County corn with those of Kimball County corn, we have the following ratios: Stalk height, 100:60; ear height, 100:35; leaf area, 100:36; stover weight, 100:49; ear weight, 100:24; grain weight, 100:20; total plant substance, 100:34; shelling percentage, 100:84; leaf area, per unit dry matter, 100:100; ear length, 100:65; ear circumference, 100:81; kernel length, 100:73; leaf thickness, 100:96; thickness of upper epidermis, 100:97; thickness of lower epidermis, 100:97; number of vascular bundles per unit of cross-section of leaf, 100:104; number of stomata per square millimeter of upper epidermis, 100:113, and of lower epidermis, 100:115; length of stoma of upper epidermis, 100:89, and of lower epidermis, 100:90; length of epidermal cell of upper epidermis, 100:92, and of lower epidermis, 100:97; and width of epidermal cell of upper epidermis, 100:99, and of lower epidermis, 100:92.

The immediate effect of moving corn from its native environment to less favorable conditions, climate being the chief variable factor, is generally a reduction in both vegetative growth and grain production. The stunting growth effect extends to the cell unit, which in turn is accompanied by histological changes that can not apparently be regarded as of an adaptive nature. These changes may be illustrated by comparison of native Lancaster County corn when grown at home and when grown in the more adverse region of Kimball County. Using the Lancaster County crop as a basis, the relative results were as follows: Plant height, 100 and 80; ear height, 100 and 52; leaf area, 100 and 78; stover weight, 100 and 62; ear weight, 100 and 1; grain weight, 100 and 0.8; total dry matter,

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100 and 26; shelling per cent, 100 and 63; leaf area per gram of dry matter, 100 and 300; ear length, 100 and 40; ear circumference, 100 and 44; leaf thickness, 100 and 100; average epidermal thickness, 100 and 97; cuticular thickness, 100 and 103; number of vascular bundles per unit of cross section of leaf, 100 and 116; average number of stomata per unit leaf area, 100 and 107; average length of stomata, 100 and 97; average length of stomatal aperture, 100 and 90; average length of epidermal cell, 100 and 95; average width of epidermal cell, 100 and 95. Altho the slightly reduced length of the stomatal aperture taken by itself might be interpreted as an adaptive reaction to retard transpiration, yet this is contradicted by an increase in the relative number of stomata.

On the other hand, moving corn to more favorable conditions than its native habitat accelerated the vegetative growth and grain production. This stimulating growth effect extended to the cell unit with its accompanying histological changes which again can not be regarded as adaptive in nature. As a parallel illustration with the preceding case, native Kimball County corn grown at home may be compared with the same corn planted in the more favorable region of Lancaster County. The changes occurring as a result of this transfer practically reversed those of the preceding case in which corn was moved to less favorable conditions. Thus, basing results on the Kimball County crop as 100 per cent, the following relative values are had: Plant height, 100 and 129; ear height, 100 and 154; leaf area, 100 and 140; stover weight, 100 and 161; ear weight, 100 and 135; grain weight, 100 and 131; total dry matter, 100 and 146; shelling per cent, 100 and 97; leaf area per gram of dry matter, 100 and 96; ear length, 100 and 113; ear circumference, 100 and 107; leaf thickness, 100 and 109; average epidermal thickness, 100 and 106; average cuticular thickness, 100 and 91; number of vascular bundles per unit cross section of leaf, 100 and 96; average number of stomata per unit leaf area, 100 and 90; average length of stomata, 100 and 111; average length of stomatal aperture, 100 and 122; average length of epidermal cell, 100 and 105; average width of epidermal cell, 100 and 108.

The actual hereditary difference between types adapted to favorable and to unfavorable climatic conditions may perhaps

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numbers of vascular bundles, number of stomata per unit leaf area, and size of stomata. A slightly shorter stomatal aperture accompanied by a slightly smaller epidermal cell appears to be characteristic of the short season dry land types of western Nebraska. Such a shortening of stomatal aperture is not, however, effective in checking the transpiration rate per unit leaf area.

During four years Kimball County and Lancaster County corn were compared by the potometer method as to their relative transpiration rates. The Lancaster County plants which were 51 per cent taller, had 88 per cent greater leaf area and 79 per cent greater dry matter than the Kimball County corn, used 81 per cent more water per plant, 3 per cent less water per unit leaf area, and equal amounts of water per unit dry plant substance produced. In a comparison of two varieties each from western and eastern Nebraska and from New York state, the seasonal transpiration per unit leaf area was respectively, 102, 101, and 100 grams. The corresponding total plant transpiration for seed from the above three sources was respectively, 85.778, 114.653, and 97.218 kilograms. The data indicate that adaptation of corn to a region of moisture shortage consists in the reduction of vegetative development and consequent reduction in the amount of water used by the individual plant.

In a comparative two-year yield test at the Experiment Station of corn types representing twelve distinct regional areas within the State, those from nearest home yielded the most. When these types are grouped into eastern, central, and western Nebraska groups, the yields were respectively, 59.8, 46.2, and 31.6 bushels per acre. These yields are for equal planting rates normal for adapted types in Lancaster County. The corresponding maturity dates were: September 24, September 21, and September 12.

In a three year comparison at the Nebraska Experiment Station of: (1) Native Experiment Station Hogue's Yellow Dent corn, (2) seed from nine local farmers, and (3) seed from seven distant eastern Nebraska farmers, the relative grain yields of the three groups were respectively, 100, 94, and 91. Of corn brought to the Station from a distance, that from three southeastern counties yielded 56.9 bushels as compared with an average yield of 63.7 bushels for seed from four northeastern counties and 66.7 bushels for the home grown Hogue's Yellow Dent. The relative yields of these three groups were 85, 96, 100.

In a two-year test comparing native Nebraska Experiment Station corn with native seed from the Experiment Stations of eight neighboring states, the local seed yielded an average of ten bushels or 18 per cent more than the imported seed. Seed from several states yielded quite as well as home-grown seed. It

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may be concluded from both of the above tests that native seed is in general superior to imported seed. However, it is entirely possible to secure seed, (1) from neighboring farmers, (2) from a distance within one's own state, and (3) from other states, which may be substituted for the native home grown seed without detriment. Nevertheless, the importation of seed corn from a distance is hazardous.

Lines of greatest type similarity run diagonally across the State in a northeasterly and a southwesterly direction. Along such lines the more favorable temperature and longer growing season of the south tends to counterbalance the more favorable precipitation of the north in their effects upon the hereditary growth habits of corn. When seed corn is moved far within the State, it is usually safest to move along such lines.

Corn native to dry-land regions is often credited with especially high efficiency in grain production. In contrast with corn native to more humid regions, it is said to produce a relatively large amount of grain in proportion to its vegetative growth. The data in these investigations fail to substantiate such a relationship. To some extent at least, this apparently erroneous conception is due to faulty methods of comparison. To illustrate, small early types are frequently moved to more favorable conditions and compared there with larger types at planting rates normal for the larger corn. Such a planting rate provides relatively more optimum conditions for the individual plants of the smaller types which frequently results in a higher proportion of grain production.

As an average for 1915 and 1916, the ratio of grain to stover (stalk and leaves) for eastern, central, and western Nebraska types grown in their home environment were respectively, .98, .84, and .68. In 1916, when eastern, central, and western Nebraska types were grown under the favorable conditions of Lancaster County, the respective ratios were, 1.04, .84, and .84. When the same three groups of corn were grown in Thurston County with conditions slightly more unfavorable for the large eastern Nebraska types and yet highly favorable for the early western types, respective ratios were, .65, .82, and 1.02. When

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THE REGIONAL ADAPTATION OF CORN IN NEBRASKA

T. A. KIESSELBACH AND F. D. KEIM

OBJECT AND SCOPE OF THE INVESTIGATION

The purpose of this investigation was to determine some of the factors involved in the regional adaptation of corn. The procedure has been to make a comparative study of native corn types, known to be locally adapted to various regional areas in Nebraska thru long growth there. The work has been confined to the single species group—Zea mays indentata. No one variety of a common source is grown thruout the state, and therefore it has been impossible to keep within a single variety. It would appear that the data should indicate morphological and histological plant characteristics involved in the adaptation of dent corn to various environments, as found in Nebraska. Comparative yield tests of corn from various sources are also reported.

The growing of adapted corn is of great importance to the farmer. The simple matter of planting well adapted, rather than poorly adapted seed may determine whether he meets with success or failure in his corn growing. Corn has now been grown in all agricultural areas of the State for many years, and experience indicates that in the main fairly well adapted types are being grown. An attempt is made to analyze what constitutes such adaptation.

Altho objection has been raised by several investigators* to the use of the term "adaptation," it is used in this paper because of its popular usage, and for the reason of being most expressive of the collective phenomenon of the favorable hereditary reactions of plants to their environment. Plants should not be credited with teleologic or purposive variation. Crop adaptation results from fortuitous or chance variation, and survival of the fittest, thus coming into a greater harmony with the environment. The selective force may be either natural, or artificially directed. Hereditary character changes are involved.

*Omission of a historical review from this bulletin has been necessitated thru a lack of space.

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A distinction must be made between these adaptive changes and mere temporary growth response. Hereditary character changes in corn may occur by: (1) Mutation from an individual, thus producing a new character; (2) Mendelian recombi-

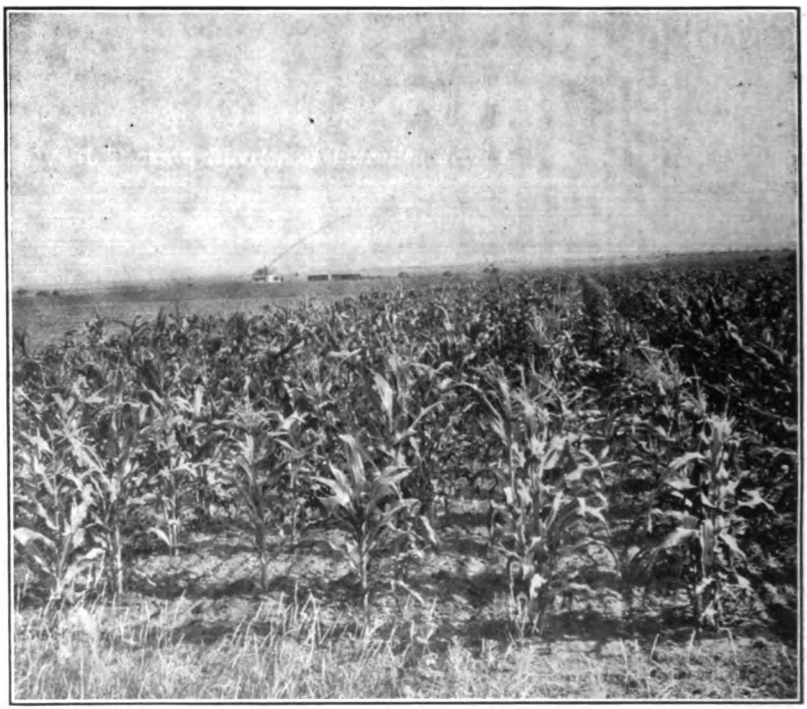

Fig. 1—A typical field of corn in western Nebraska.

nation of unit characters resulting in new forms; and (3) segregation of the more suitable types present in a mixed population.

Since the crop environment of any locality is necessarily somewhat fluctuating or variable from year to year, important crop adaptation characteristics are congenial for the most part to the mean or normal conditions. A crop can not be in full accord every year with a fluctuating environment. Consequently, a crop to be well adapted from an agricultural standpoint must be capable of some adjustment to variable conditions.

Adaptation occurs as a favorable reaction to some one or more growth factors of the environment. The environmental conditions which are apt to become limiting factors in Ne-

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braska's corn crop are heat, moisture, and soil fertility. Nebraska's great regional diversity of crop growing conditions affords a splendid opportunity for this study. The environmental and corn types surveys follow.

Fig. 2—A typical field of corn in eastern Nebraska.

THE ENVIRONMENTAL SURVEY OF NEBRASKA'S CORN GROWING CONDITIONS

Climate and soil are the chief variable growth factors in the State, where corn is grown, and variations within these appear to be almost wholly responsible for the widely differing corn types found in various parts of the State.

Climatic differences may be readily analyzed, and their collective effects on corn are very apparent. The effects of regional soil differences are far less pronounced. In general, thruout the State where corn is grown, the land is fertile and capable of producing large crops. Greater local than regional differences

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in soil fertility are found with the exception perhaps of the great Sand Hills Area of north and west central Nebraska, as compared with the balance of the State. Special adaptations to these soil differences are rather obscure. Some communities have certain favorite corns for the very fertile bottom land and others for the poorer hills and uplands. The writers have not undertaken in these investigations to substantiate these local preferences.

These investigations are especially concerned with the crop growing conditions in twelve counties in different parts of the State, namely: Richardson, Lancaster, Washington, Thurston, Holt, Nuckolls, Kearney, Lincoln, Cherry, Grant, Kimball and Dawes. It is for corn grown in these counties that the comparative type studies were made.

CLIMATE

The climatic considerations of primary importance in a study of the environment as related to the regional adaptation of corn are: (1) Temperature, (2) precipitation, and (3) atmospheric power for evaporation. The accompanying climatic data are based largely upon observations made by the United States Weather Bureau.* The normal climate of any region is best represented by the average for a large number of years. Thirty or more years have been averaged in the following data.

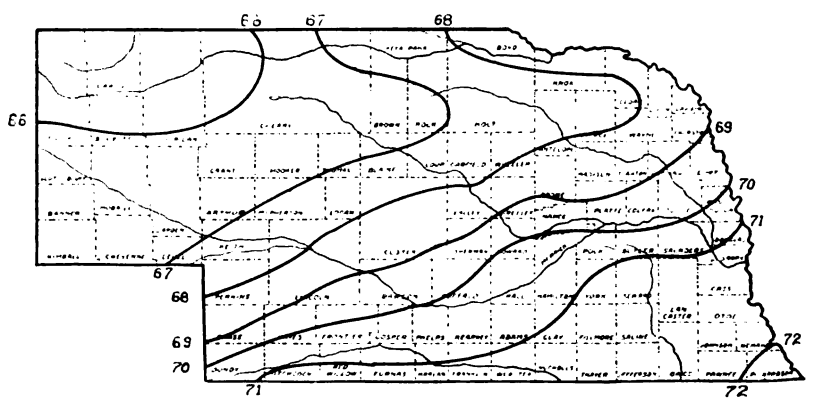

Fig. 3—Normal isotherms for the corn growing season of May, June, July, and August. (Degrees F.)

*The writers are indebted to Director G. A. Loveland of the Nebraska Section of

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The seasonal rainfall and temperature for the years 1915 and 1916 are also given for the twelve localities in the State where corn types were studied in detail during those years.

REGIONAL TEMPERATURE VARIATIONS WITHIN THE STATE

Important aspects of temperature related to these studies are: (1) mean temperature of the corn growing season, (2) duration of the frost-free growing season, and (3) occurrence of excessive temperatures of short duration, especially when accompanied by abnormally high wind velocity.

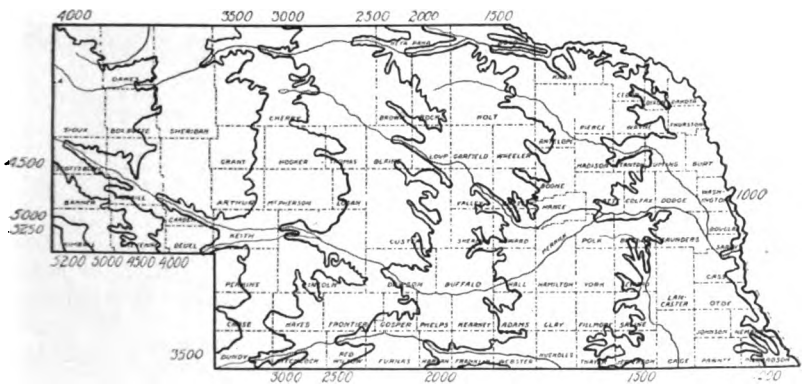

Fig. 4—Altitude variation (in feet) in Nebraska. (After Warren.) The south to north width of the state is 210 miles, or 3 degrees latitude. The east to west length is 425 miles.

NORMAL MEAN TEMPERATURE

We are more concerned with the mean temperature of the corn growing season than with the mean annual temperature. Accordingly, variations thruout the State in the normal mean temperature for the period of May to August, inclusive, have been compiled and are charted in Figure 3. In response chiefly to differences in latitude, this mean seasonal temperature is found to decrease approximately four degrees from the southern to the northern border of the State. Due to the combined effects of increased latitude and altitude, (Figure 4), the corresponding mean temperature of extreme western Nebraska is seven degrees lower than for extreme southeastern Nebraska. The altitude rises rather continually from 1,000 feet in the southeast to a maximum of about 5,300 feet in the west. In general, the isotherms run from the northeast to the southwest.

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NORMAL LENGTH OF FROST-FREE GROWING SEASON

The length of the frost-free period between the last killing frost in the spring and the first killing frost in autumn, (Figures 5 and 6), is expressive of the relative length of the growing season available to corn in various parts of the State. The mean duration of the frost-free period in the extreme southeast is approximately 171 days, as compared to 121 days in the northwest. The lines of equal frost dates tend to run in a northeasterly direction.

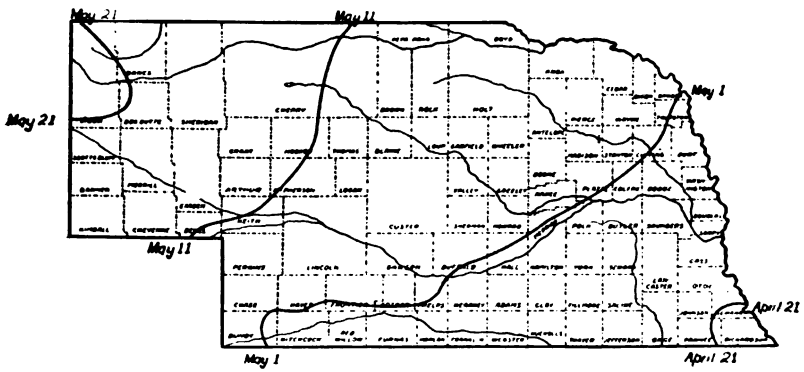

Fig. 5—Average dates of last killing frost in spring.

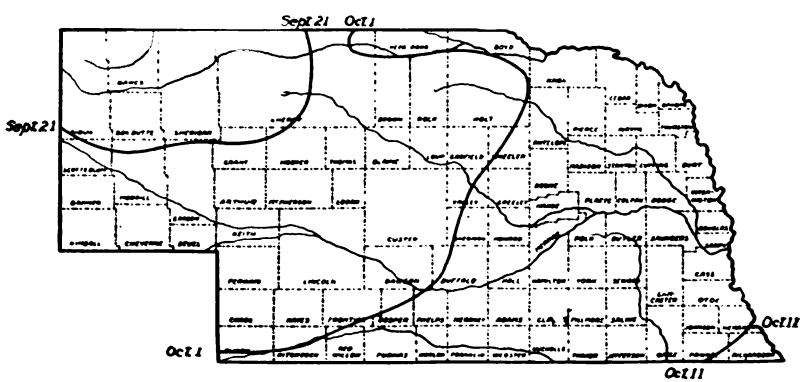

Fig. 6—Average dates of first killing frost in autumn.

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as a summary expression of temperature, relative humidity, and wind velocity; and (3) absorptive and retentive character of the soil for moisture.

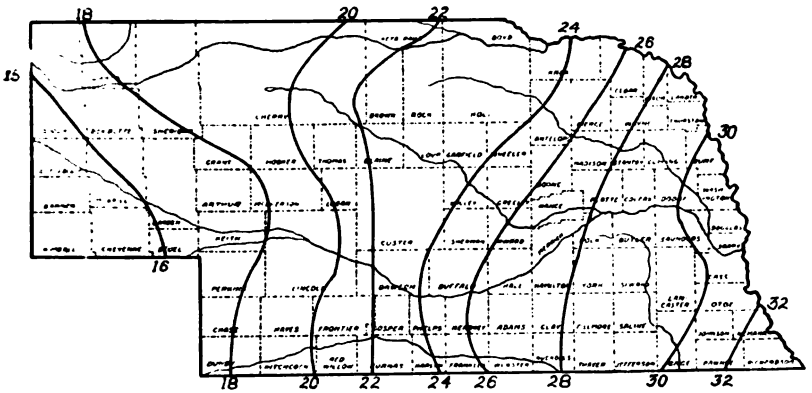

Fig. 7—Average annual precipitation for the different sections of Nebraska. (Inches.)

MEAN ANNUAL PRECIPITATION

As shown in Figure 7, the annual precipitation falls rather gradually from 32 inches in the extreme southeast to 16 inches in the extreme western part of the State. In the eastern two-thirds of the State the lines of equal rainfall run in a somewhat northeasterly direction. The character and distribution of the rainfall is rather uniform thruout the State, being of the torrential type and coming largely during the crop growing season. (Table 1.)

TABLE 1.—*Normal Monthly Distribution of Rainfall in Nebraska. Average of Entire State for Thirty Years.*

Month	Inches	Month	Inches
January	.68	July	3.51
February	.71	August	2.62
March	1.16	September	1.84
April	2.40	October	1.49
May	3.60	November	.68
June	3.93	December	.69

Average annual rainfall, 23.31 inches.

EVAPORATION RATE

The power of the atmosphere to evaporate water has a marked influence upon the effectiveness of the rainfall. Data

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Map showing the Soil Regions of Nebraska. (By Condra, director Nebraska Soil Survey.) Numbers 1 to 14 represent the divisions of the High Plains Region. The divisions are 1, Perkins Plain; 2, Cheyenne Table; Pumpkin Creek Valley; 4, Wildcat Ridge; 5, North Platte Valley; 6, Box Butte Table; 7, Niobrara Valley; Dawes Table; 9, Pine Ridge; 10, Hat Creek Basin; 11, White River Basin; 12, Springview Table; 13, Ainsworth Table; 14, Holt Plain.

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LE 2.—*Summary of Normal Climatic Conditions, Altitude, and Soil Type at Various Points in the State Where Corn Types Were Studied.*†

County	Mean temperature of corn growing season*	Last spring frost	First fall frost	Length of frost free period	Annual precipitation	Altitude	Kind of soil
	Degrees F.	*Date*	*Date*	*Days*	*Inches*	*Feet*	
ardson	73–72	4–21	10–11	173	32	900	Glacial silt loam
ington	71–70	4–26	10–5	162	31	1,000	Loess
ston	69–68	5–1	10–1	153	29	1,100	Loess
aster	71–72	4–25	10–9	167	29	1,200	Loess terrace
colls	71–72	4–27	10–5	161	28	1,700	Loess
ney	70–69	4–29	10–2	156	26	2,200	Loess
	68–67	5–7	9–28	144	23	1,700	Fine sandy loam
oln	69–68	5–8	9–25	140	20	3,100	Sandy loess
ry	67–66	5–11	9–23	135	20	3,000	Fine sandy loam
t	67–66	5–13	9–21	131	18	3,500	Sandy loam
es	66–65	5–17	9–19	125	18	3,800	Fine sandy loam
ball	66–65	5–14	9–23	132	16	4,800	Fine sandy loam

†Data constructed from Figures 3 to 8.
*May, June, July, August.

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caster	71–72	4–25	10–9	167	29	1,200	Loess terrace
kolls	71–72	4–27	10–5	161	28	1,700	Loess
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ball	66–65	5–14	9–23	132	16	4,800	Fine sandy loam

†Data constructed from Figures 3 to 8.
*May, June, July, August.

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are not available to show the relative differences in evaporation rate for different parts of the State. It is quite likely, however, that as we progress in a northwesterly direction, the accelerating evaporation effects of a lower humidity are in part offset by the reduced temperature. The evaporation rate is unquestionably reduced from the south to the north. Most of the country south of the Platte River is subject to occasional detrimental hot winds with excessive evaporation power, while such winds are seldom known farther north.

ABSORPTIVE AND RETENTIVE POWER OF THE SOIL

Regionally, the soil differs somewhat in absorptive and retentive power due primarily to a difference in texture. The soils of central and western Nebraska are somewhat more porous than eastern soils, and consequently less subject to runoff. In

TABLE 3. — *Precipitation During Five Spring and Summer Months in Regions Where Corn Adaptation Studies Were Located. 1915.*

Location	Precipitation					
	April	May	June	July	August	Total
County (1)	*Inches* (2)	*Inches* (3)	*Inches* (4)	*Inches* (5)	*Inches* (6)	*Inches* (7)
EASTERN NEBRASKA						
Richardson	1.87	7.62	5.69	9.93	5.28	30.39
Washington	1.25	7.72	4.45	8.55	2.92	24.89
Thurston	.60	5.92	7.74	6.95	2.45	23.66
Lancaster	1.37	4.77	4.03	6.74	5.57	22.48
Nuckolls	1.92	5.17	9.71	4.94	3.29	25.03
Average	1.40	6.24	6.32	7.43	3.90	25.29
CENTRAL NEBRASKA						
Kearney	3.06	6.04	8.44	7.96	6.84	32.34
Holt	2.63	4.85	5.17	5.30	1.31	19.26
Lincoln	7.10	5.55	3.39	4.66	4.23	24.93
Cherry	3.46	3.84	4.52	7.40	.89	20.11
Average	4.06	5.07	5.38	6.33	3.32	24.16
WESTERN NEBRASKA						
Grant*	6.31	4.62	6.81	4.27	5.65	27.66
Dawes	2.93	3.16	4.84	2.99	5.11	19.03
Kimball	5.03	3.05	3.53	1.07	1.75	14.43

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the Sand Hills Area of north and west central Nebraska there is probably justification for the belief that the type of soil found there is more resistant to atmospheric evaporation of soil moisture than are the heavier soils elsewhere.

SOIL FERTILITY

Regionally, with the exception of much of the Sand Hills Area and north and west central Nebraska, the soils of this State that are not subject to serious erosion are fertile, and the regional adaptation of corn is probably not greatly influenced by difference in soil fertility. The accompanying soil map by Condra indicates the general soil areas found.

TABLE 4. — *Precipitation During Five Spring and Summer Months in Regions Where Corn Adaptation Studies Were Located. 1916.*

Location	Precipitation					
	April	May	June	July	August	Total
County (1)	*Inches* (2)	*Inches* (3)	*Inches* (4)	*Inches* (5)	*Inches* (6)	*Inches* (7)
EASTERN NEBRASKA						
Richardson	3.09	8.24	2.64	2.73	6.72	23.42
Cass	2.21	4.60	4.33	.73	7.01	18.88
Thurston	.73	5.16	3.07	.83	3.71	13.50
Lancaster	2.69	3.48	3.11	1.29	6.70	17.27
Nuckolls	2.08	4.30	3.45	.35	1.67	11.85
Average	2.16	5.16	3.32	1.19	5.16	16.98
CENTRAL NEBRASKA						
Kearney	3.78	3.13	3.66	.92	6.85	18.34
Holt	.80	4.25	3.28	.90	2.18	11.41
Lincoln	.72	1.95	3.09	.59	2.35	8.70
Cherry	.59	3.42	3.15	1.95	4.45	13.56
Average	1.47	3.19	3.29	1.09	3.96	13.00
WESTERN NEBRASKA						
Grant	.49	2.15	2.32	2.77	3.40	11.13
Dawes	1.15	4.97	3.44	2.38	.82	12.76
Kimball	1.07	3.70	.93	2.75	1.61	10.06
Average	.90	3.61	2.23	2.63	1.94	11.32

SUMMARY OF CONDITIONS WHERE CORN TYPES WERE STUDIED

NORMAL REGIONAL DIFFERENCES

The approximate normal environmental differences between the various localities where the following corn type survey was

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made are compiled in Table 2 from the preceding charts. Striking regional climatic differences will be noted.

TEMPERATURE AND RAINFALL DURING 1915 AND 1916

Tables 3 to 6 show the temperature and rainfall during the crop growing season for localities where corn types were studied. A knowledge of these conditions may help account for certain

TABLE 5.—*Mean Temperature During Four Spring and Summer Months in Regions Where Corn Adaptation Studies Were Located. 1915.*

Location	Mean Temperature				
	May	June	July	August	Average
County (1)	*Degrees F.* (2)	*Degrees F.* (3)	*Degrees F.* (4)	*Degrees F.* (5)	*Degrees F.* (6)
EASTERN NEBRASKA					
Richardson	61.6	69.8	72.8	69.6	68.4
Washington	58.4	66.0	70.0	65.9	65.1
Thurston	57.2	65.6	69.6	65.2	64.4
Lancaster	59.0	67.2	71.7	67.9	66.4
Nuckolls	60.0	67.4	72.4	69.0	67.2
Average	59.2	67.2	71.3	67.5	66.3
CENTRAL NEBRASKA					
Kearney	57.5	65.6	71.6	68.6	65.8
Holt	53.8	63.1	67.2	66.4	62.6
Lincoln	55.2	63.8	69.4	68.2	64.1
Cherry	52.7	62.0	67.6	66.4	62.2
Average	54.8	63.6	68.9	67.4	63.7
WESTERN NEBRASKA					
Grant*	52.7	61.4	67.0	66.2	61.8
Dawes	53.2	61.6	66.9	68.0	62.4
Kimball	51.8	60.0	66.5	66.0	61.1
Average	52.5	61.0	66.8	66.7	61.8

*Temperature data in Grant County were not available for 1915, and data from Arthur County, bordering on the south, have been supplied.

apparent inconsistencies in the comparative plant characters. The

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TABLE 6.—*Mean Temperature During Four Spring and Summer Months in Regions Where Corn Adaptation Studies Were Located. 1916.*

Location	Mean Temperature				
	May	June	July	August	Average
County (1)	*Degrees F.* (2)	*Degrees F.* (3)	*Degrees F.* (4)	*Degrees F.* (5)	*Degrees F.* (6)
EASTERN NEBRASKA					
Richardson	64.4	70.3	81.9	78.7	73.8
Cass	62.0	66.5	79.6	74.7	70.7
Thurston	60.2	64.9	80.1	73.2	69.6
Lancaster	62.2	67.8	82.1	75.8	72.0
Nuckolls	56.8	63.8	81.0	76.8	69.6
Average	61.1	66.7	80.9	75.8	71.1
CENTRAL NEBRASKA					
Kearney	60.7	66.2	80.0	74.4	70.3
Holt	55.0	63.7	79.5	72.8	67.7
Lincoln	58.2	64.6	80.0	74.0	69.2
Cherry	55.0	62.2	79.2	71.2	66.9
Average	57.2	64.2	79.7	73.1	68.5
WESTERN NEBRASKA					
Grant	52.5	60.0	70.5	67.6	62.6
Dawes	54.6	62.8	78.0	69.9	66.3
Kimball	53.3	63.0	74.2	68.3	64.7
Average	53.5	61.9	74.2	68.6	64.5

THE CORN TYPES SURVEY OF NEBRASKA

TWO CLASSES OF INVESTIGATIONS

Data having been presented to show the widely different growing conditions in various regions of the State, we may proceed to the comparison of corn types which are found adapted to these conditions. The plant characters were determined by detail measurments, the results of which are summarized in tabular form.

The corn types survey may be divided into two main sorts

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grouped to represent more general regional areas. In the tables, the data are assembled by localities into eastern, central, and western Nebraska groups.

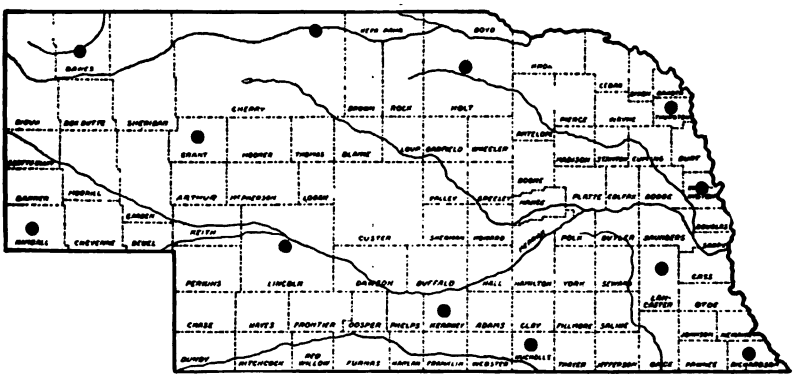

Fig. 9—Sources of native corn types used in these investigations, 1915 and 1916.

NATIVE CORN TYPES GROWN AT HOME

MORPHOLOGICAL CHARACTERS

METHODS OF STUDY

During the years 1915 and 1916, detailed measurements were made of representative corn types grown in twelve counties scattered thruout the State. On an average, four representative fields were chosen in each county, and ten successive plants measured in a representative part of each field. The morphological characters measured were: (1) Height of stalk, (2) height of ear, (3) leaf area, (4) grain weight, (5) ear weight, (6) stover weight, (7) total plant weight, (8) shelling per cent, (9) leaf area per gram dry matter produced, (10) length of ear, (11) circumference of ear, (12) length of kernel, (13) width of kernel. Bags were kept in the field for systematically gathering the dry leaves of the selected plants

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readily visible by giving relative rather than actual figures. In this table the ratios are based upon the measurments for Richardson County corn as 100 per cent. Richardson County, being situated in the extreme southeastern part of the State, has normally the longest growing season, highest temperature, and greatest precipitation in the State.

By comparing the results for Richardson and Kimball Counties the reaction of corn types adapted to the two most extreme environments may be observed. Based on Richardson County corn measurments as 100 per cent, relative values for Kimball County were as follows: (1) Height of stalk, 60; (2) height of ear, 30; (3) leaf area, 37; (4) stover weight, 41; (5) ear weight, 28; (6) total dry matter, 33; (7) grain weight, 25; (8) shelling per cent, 89; (9) leaf area per gram dry matter, 108; (10) ear length, 67; (11) ear circumference, 80; (12) kernel length, 76; (13) kernel width, 106; and (14) kernel weight, 58. Other counties may be compared in a similar manner. With some irregularities which are due perhaps in part to low frequency of plants studied, the data for the various counties suggest that the more adverse the conditions, the more dwarfish is the growth habit of adapted types of corn.

With the twelve counties under observation, grouped into three State regions from east to west (Table 11), the same principles are brought out. Based on eastern Nebraska measurements as 100 per cent, relative values for eastern, central and western Nebraska were respectively as follows: (1) Height of stalk, 100, 78, and 68; (2) height of ear, 100, 66, and 40; (3) leaf area, 100, 67, and 44; (4) stover weight, 100, 74, and 50; (5) ear weight, 100, 67, and 39; (6) total dry matter, 100, 70, and 44; (7) grain weight, 100, 63, and 35; (8) shelling per cent, 100, 95, and 89; (9) leaf area per gram dry matter, 100, 95 and 98; (10) ear length, 100, 90, and 79; (11) ear circumference, 100, 94, and 84; (12) kernel length, 100, 93, and 84; (13) kernel width, 100, 103, and 101; (14) kernel weight, 100, 85, and 61.

HISTOLOGICAL CHARACTERS

METHODS OF STUDY

Since the leaf is the seat of food synthesis and of transpiration, it would appear that the most important special histological adaptations, if any, would occur there. Therefore, rather detailed microscopic leaf studies were made for all the plants harvested in seven of the counties previously reported.

At the time of measuring the leaf area, about two weeks after tasseling, a leaf sample for sectioning was taken, by means

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TABLE 7.—*Plant Characteristics of Native Corn Types Grown in Various Regions of Nebraska. 1915.*

Where grown	Plant measurements			Dry matter				Shelling per cent	Leaf area per gram dry matter	Ear measurements		Kernel measurements		
	Height of stalk	Height of ear	Leaf area	Stover	Ear	Total	Grain			Length	Circumference	Length	Width	Weight
County (1)	*Feet* (2)	*Feet* (3)	*Sq. In.* (4)	*Grams* (5)	*Grams* (6)	*Grams* (7)	*Grams* (8)	*Per cent* (9)	*Sq. In.* (10)	*Inches* (11)	*Inches* (12)	*Inches* (13)	*Inches* (14)	*Grams* (15)
EASTERN NEBRASKA														
Richardson..	8.7	3.2	1,293	216	323	539	275	85	2.4	8.1	6.7	.56	.31	.313
Washington..	9.6	4.1	1,386	227	307	534	258	84	2.6	8.2	7.0	.56	.32	.299
Thurston....	7.7	2.9	1,048	157	165	322	132	80	3.3	7.0	6.0	.49	.31	.200
Lancaster....	8.3	4.3	1,222	221	195	416	164	84	2.9	7.0	6.0	.45	.31	.222
Nuckolls....	7.4	2.8	1,174	189	261	450	219	84	2.6	7.5	6.5	.42	.36	.332
Average...	8.3	3.5	1,225	203	250	452	210	83	2.8	7.6	6.4	.50	.32	.273
CENTRAL NEBRASKA														
Kearney.....	7.1	2.9	899	168	214	382	178	83	2.4	7.3	6.4	.51	.32	.256
Holt.....	6.6	2.3	746	112	100	212	172	72	3.5	6.1	5.5	.41	.32	.163
Lincoln.....	6.4	2.3	724	149	193	342	154	80	2.0	7.2	6.0	.47	.34	.273
Cherry.....	6.3	2.0	692	128	116	244	87	75	2.9	6.1	5.5	.42	.34	.192
Average...	6.6	2.4	765	139	156	295	123	77	2.7	6.7	5.8	.45	.33	.221
WESTERN NEBRASKA														
Grant.....	6.1	2.1	746	142	70	212	42	60	3.5	6.3	5.4	.43	.28	.102
Dawes.....	6.1	1.8	601	108	99	207	72	73	2.9	6.0	5.6	.41	.32	.160
Kimball.....	5.2	1.1	470	106	79	185	56	71	2.5	5.3	5.4	.41	.36	.188
Average..	5.8	1.7	606	119	83	202	57	68	3.0	5.9	5.5	.42	.32	.150

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8.—*Plant Characteristics of Native Corn Types Grown in Various Regions of Nebraska. 1916.*

Grown	Plant measurements			Dry matter				Shelling per cent	Leaf area per gram dry matter	Ear measurements		Kernel measurements		
	Height of stalk	Height of ear	Leaf area	Stover	Ear	Total	Grain			Length	Circumference	Length	Width	Weight
ty	*Feet* (2)	*Feet* (3)	*Sq. In.* (4)	*Grams* (5)	*Grams* (6)	*Grams* (7)	*Grams* (8)	*Per cent* (9)	*Sq. In.* (10)	*Inches* (11)	*Inches* (12)	*Inches* (13)	*Inches* (14)	*Grams* (15)
EASTERN NEBRASKA														
son..	9.2	3.9	1,274	221	274	495	233	85	2.6	7.9	6.5	.50	.32	.327
ton..	8.6	3.9	1,269	222	282	504	242	86	2.5	8.3	6.3	.50	.30	.308
n....	7.5	3.3	1,138	176	162	338	133	82	3.4	6.6	5.7	.46	.30	.254
er....	7.4	3.9	1,295	160	208	368	177	85	3.5	7.1	5.8	.44	.30	.290
s....	6.3	2.8	1,122	197	135	332	108	80	3.4	5.9	5.2	.47	.33	.309
ge...	7.8½	3.6½	1,220	195	212	407	179	84	3.1	7.2	5.9	.47	.31	.289
CENTRAL NEBRASKA														
.....	6.8	3.2	1,029	219	171	390	142	83	2.6	6.8	6.0	.48	.31	.254
.....	6.8	2.3	973	149	181	330	147	81	2.9	7.0	6.0	.45	.33	.257
.....	5.1	1.7	793	124	124	248	99	80	3.2	6.2	5.4	.44	.32	.281
.....	5.4	1.7	699	128	142	270	114	80	2.6	6.3	5.4	.44	.32	.271
ge...	6.0	2.2	873	155	154	309	125	81	2.8	6.6	5.7	.45	.32	.266
WESTERN NEBRASKA														
.....	4.9	1.2	504	76	80	156	62	78	3.2	5.7	4.3	.37	.32	.186
.....	5.0	1.2	467	89	121	210	98	81	2.2	6.1	5.3	.43	.32	.224
.....	5.7	1.0	468	71	89	160	72	81	2.9	5.5	5.2	.40	.31	.183
ge...	5.2	1.1	480	79	97	176	77	80	2.8	5.8	4.9	.40	.32	.198

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TABLE 9.—*Plant Characteristics of Native Corn Types Grown in Various Regions of Nebraska. (Average for 1915 and 1916.)*

Where grown	Plant measurements			Dry matter				Shelling per cent	Leaf area per gram dry matter	Ear measurements		Kernel measurements		
	Height of stalk	Height of ear	Leaf area	Stover	Ear	Total	Grain			Length	Circumference	Length	Width	Weight
County (1)	*Feet* (2)	*Feet* (3)	*Sq. In.* (4)	*Grams* (5)	*Grams* (6)	*Grams* (7)	*Grams* (8)	*Per cent* (9)	*Sq. In.* (10)	*Inches* (11)	*Inches* (12)	*Inches* (13)	*Inches* (14)	*Grams* (15)
EASTERN NEBRASKA														
Richardson	8.95	3.50	1,283.5	218.5	298.5	517.0	254.0	85	2.50	8.00	6.6	.530	.315	.3200
Washington	9.10	4.00	1,327.5	224.5	294.5	519.0	250.0	85	2.55	8.25	6.65	.530	.310	.3035
Thurston	7.60	3.10	1,093.0	166.5	163.5	330.0	132.5	81	3.3	6.80	5.85	.475	.305	.2270
Lancaster	7.80	4.10	1,258.5	190.5	201.5	392.0	170.5	84.5	3.2	7.05	5.90	.445	.305	.2560
Nuckolls	6.80	2.80	1,148.0	193.0	198.0	391.0	163.5	82	3.0	6.70	5.85	.445	.345	.3205
Average	8.05	3.50	1,222.1	198.6	231.2	429.8	194.1	83.5	2.89	7.36	6.17	.485	.316	.2854
CENTRAL NEBRASKA														
Kearney	6.90	3.05	964.0	193.5	192.5	386.0	160.0	83	2.50	7.05	6.20	.495	.315	.255
Holt	6.70	2.30	859.5	130.5	140.5	271.0	107.4	76.5	3.10	6.55	5.75	.430	.325	.210
Lincoln	5.70	2.00	758.5	136.5	158.5	295.0	126.8	80	2.60	6.70	5.70	.455	.330	.277
Cherry	5.80	1.85	695.5	128.0	129.0	257.0	100.5	77.5	2.70	6.20	5.45	.430	.330	.2315
Average	6.27	2.30	819.4	147.1	155.1	302.2	123.2	79.2	2.75	6.62	5.77	.452	.325	.2434
WESTERN NEBRASKA														
Grant	5.50	1.65	625.0	109.0	75.0	184.0	52.0	69	3.3	6.0	4.85	.400	.300	.1440
Dawes	5.50	1.50	534.0	98.5	110.0	208.5	85.0	77	2.5	6.05	5.45	.420	.320	.1920
Kimball	5.40	1.05	469.0	88.5	84.0	172.5	64.0	76	2.7	5.40	5.30	.405	.335	.1855
Average	5.47	1.40	542.7	98.7	89.7	188.4	67.0	74	2.83	5.82	5.20	.408	.318	.1738

Data in column 10 are the average of ratios rather than the ratio of averages.

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TABLE 10.—*Plant Characteristics of Native Corn Types Grown in Various Regions of Nebraska. The results for the various counties are here expressed in per cent of the results for Richardson County. (Average for 1915 and 1916.)**

Where grown	Plant measurements			Dry matter				Shelling per cent	Leaf area per gram dry matter	Ear measurements		Kernel measurements		
	Height of stalk	Height of ear	Leaf area	Stover	Ear	Total	Grain			Length	Circumference	Length	Width	Weight
County (1)	*Per cent* (2)	*Per cent* (3)	*Per cent* (4)	*Per cent* (5)	*Per cent* (6)	*Per cent* (7)	*Per cent* (8)	*Per cent* (9)	*Per cent* (10)	*Per cent* (11)	*Per cent* (12)	*Per cent* (13)	*Per cent* (14)	*Per cent* (15)
EASTERN NEBRASKA														
Richardson	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Washington	102	114	103	103	99	100	98	100	102	103	101	100	98	95
Thurston	85	89	85	76	55	64	52	95	132	85	89	90	97	71
Lancaster	87	117	98	87	67	76	67	99	128	88	89	84	97	80
Nuckolls	76	80	89	88	66	76	64	96	120	84	89	84	109	100
CENTRAL NEBRASKA														
Kearney	77	87	75	89	64	75	63	98	100	88	94	93	100	80
Holt	75	66	67	60	47	52	42	90	124	82	87	81	103	66
Lincoln	64	57	59	62	53	57	50	94	104	84	86	86	105	87
Cherry	65	53	54	59	43	50	40	91	108	77	83	81	105	72
WESTERN NEBRASKA														
Grant	62	47	49	50	25	36	20	81	132	75	73	75	95	45
Dawes	62	43	42	45	37	40	33	91	100	76	83	79	102	60
Kimball	60	30	37	40	28	33	25	89	108	67	80	76	106	58

*Data calculated from Table 9.

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TABLE 11.—*Summary* of Plant Characteristics of Native Corn Types Grown in Various Regions of Nebraska. (Average for 1915 and 1916.)*

Region in Nebraska where grown	Plant measurements			Dry matter				Shelling per cent	Leaf area per gram dry matter	Ear measurements		Kernel measurements		
	Height of stalk	Height of ear	Leaf area	Stover	Ear	Total	Grain			Length	Circumference	Length	Width	Weight
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
ACTUAL VALUES														
	Feet	*Feet*	*Sq. In.*	*Grams*	*Grams*	*Grams*	*Grams*	*Per cent*	*Sq. In.*	*Inches*	*Inches*	*Inches*	*Inches*	*Grams*
Eastern (Av., 5 Co.)	8.05	3.50	1,222.1	198.6	231.2	429.8	194.1	83.5	2.89	7.36	6.17	.485	.316	.2854
Central (Av., 4 Co.)	6.27	2.30	819.4	147.1	155.1	302.2	123.2	79.2	2.75	6.62	5.77	.452	.325	.2434
Western (Av., 3 Co.)	5.47	1.40	542.7	98.7	89.7	188.4	67.0	74.0	2.83	5.82	5.20	.408	.318	.1738
RELATIVE VALUES														
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Eastern (Av., 5 Co.)	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Central (Av., 4 Co.)	78	66	67	74	67	70	63	95	95	90	93	93	103	85
Western (Av., 3 Co.)	68	40	44	50	39	44	34	89	98	79	84	84	101	61

*Compiled from data in Table 9.

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of a leaf punch, from the ear leaf of each plant measured. The point of sampling was at the widest part of the leaf midway between the mid-rib and leaf margin. A quantity of adjoining upper and lower epidermis was also removed and preserved. The leaf samples were preserved in absolute alcohol for later study. Previous experience had suggested that fairly comparable data might be secured by use of a similarly situated leaf from ten different plants of each variety. The number of plants studied from any one locality ranges from thirty to sixty, representing three to six different farms. The microscopic sections were made free-hand by using small corks and a sharp razor. An extensive method study proved that the use of only a few measurements would be unreliable because of the inconsistencies of leaf structure and, therefore, a large number of duplicate counts and measurements were made. An average of five varieties were studied microscopically for each of the seven counties. Four hundred transectional leaf measurements, and 160 epidermal counts and measurements were made for each variety, averaging a total of 2,000 per county in the former case and 800 in the latter. The following measurements were taken:

Leaf Thickness—This measurement includes the cuticle of each epidermal layer. Tissue immediately adjacent to the large vascular bundles was avoided.

Epidermal Thickness—The upper and lower epidermis were measured at the same point as the leaf thickness, including the cuticle.

Vascular Bundles—Counts were made of the number of vascular bundles in the cross-sections of the leaves.

Number of Stomata in a Unit Area—The number of stomata were counted in 100 microscopic fields for both the upper and lower epidermis of each type. The microscopic fields were chosen systematically in order that the results might be representative.

Length of Stoma and Stomatal Aperture—As far as possible, representative stomata were measured. It was at times with difficulty that the stomatal aperture was measured.

Length and Width of Epidermal Cells—Since these and all other microscopic measurements were made in eye piece spaces, it was necessary to convert them into microns.

RESULTS

The results of these histological studies are contained in Tables 12 and 13. The various localities are grouped into eastern, central, and western Nebraska regions. Since these studies involve only seven of the twelve counties used in studying the

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preceding morphological adaptations, the morphological characters for these seven counties only are briefly summarized in Tables 14 and 15, in order that the histological data may be directly comparable with them.

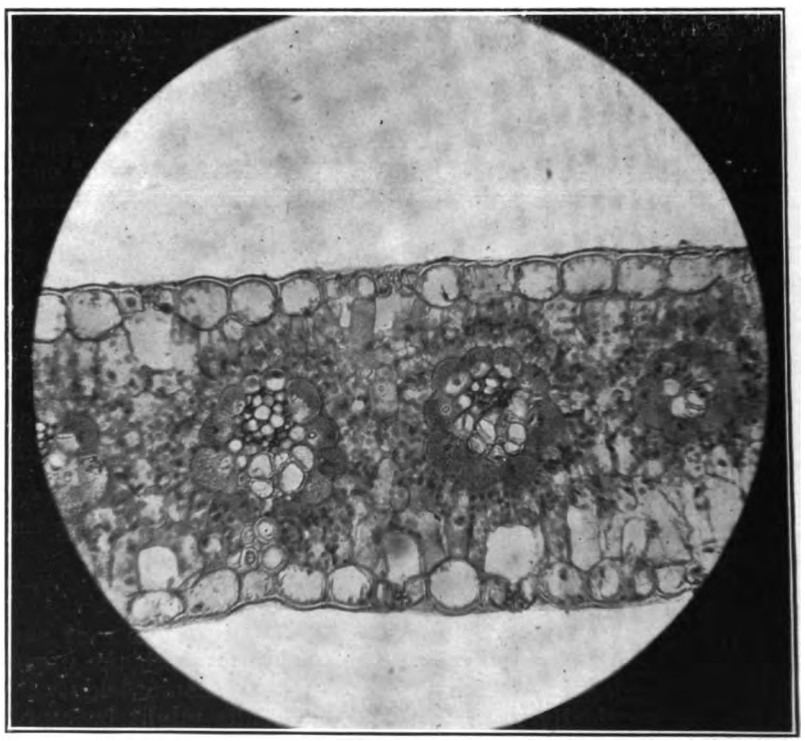

Fig. 10—Microphotograph of a cross-section of corn leaf, showing arrangement of vascular bundles, relative epidermal thickness, cuticle, and stomata. Enlarged 233 diameters.

In comparing native types grown under the two extreme conditions of Richardson County and Kimball County, it is observed that whereas the plant weight and leaf area of Kimball

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greater for Kimball County corn. Based on Richardson County corn as 100 per cent, the relative number of stomata per square millimeter of epidermis, length of stoma, and length and width of epidermal cells of Kimball County corn were respectively 114, 90, 94, and 95 per cent. Similar comparisons between other counties may be made by a study of the tables. No adaptive structural differences are to be observed.

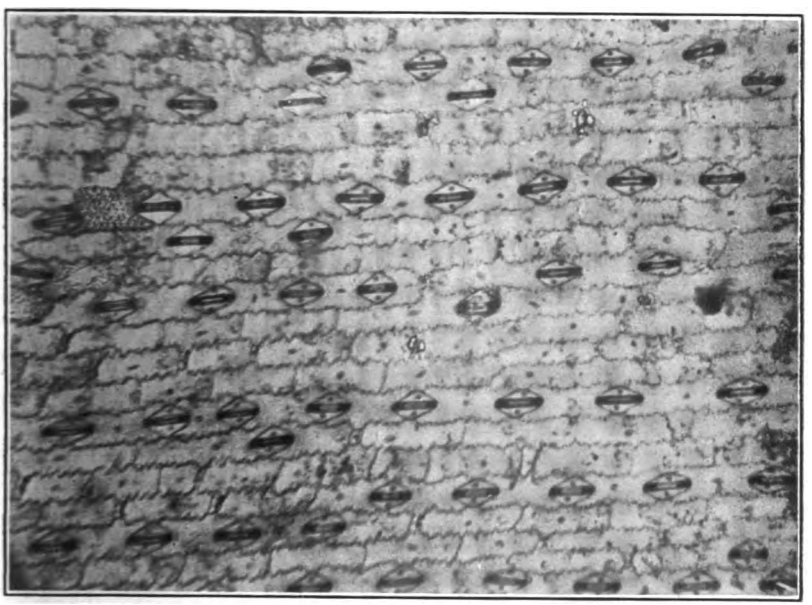

Fig. 11—Microphotograph of corn epidermis, showing epidermal cells, stomata, and stomatal apertures. Enlarged 116 diameters.

With the counties grouped into eastern, central, and western Nebraska, (Table 16), and the regional data based on eastern Nebraska as 100 per cent, we find that (1) the respective relative leaf thicknesses are, 100, 104, and 101; (2) thickness of upper epidermis, 100, 100, and 99; (3) lower epidermis, 100, 102, and 102; (4) number of vascular bundles in one centimeter of cross section, 100, 94, and 98; (5) average number of stomata per square millimeter epidermis, 100, 112, and 114; (6) average length of stomata, 100, 97, and 90; (7) average length of epidermal cell, 100, 83, and 87; and (8) average width of epidermal cell, 100, 98, and 99. The data suggest that while there is marked adaptation in morphological characters, there is no corresponding

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TABLE 12.—*Histological Leaf Measurements of Native Corn Types Grown in Various Regions of Nebraska. 1915.*

Where grown	Thickness of			Per cent of total leaf thickness of			Number vascular bundles per cm. leaf width
	Leaf	Upper epidermis	Lower epidermis	Upper epidermis	Lower epidermis	Total epidermis	
County (1)	*Microns* (2)	*Microns* (3)	*Microns* (4)	*Per cent* (5)	*Per cent* (6)	*Per cent* (7)	(8)
			EASTERN NEBRASKA				
Richardson	230.3	34.9	29.6	15.2	12.8	28.0	63.8
Lancaster	217.6	33.8	27.0	15.5	12.4	27.9	68.0
Thurston	229.8	35.4	28.1	15.4	12.2	27.6	66.2
Average	225.9	34.7	28.2	15.3	12.4	27.8	66.0
			CENTRAL NEBRASKA				
Lincoln	236.6	34.3	28.4	14.5	12.0	26.5	59.7
Cherry	232.4	35.4	29.6	15.3	12.7	28.0	63.9
Average	234.5	34.8	29.0	14.9	12.3	27.2	61.8
			WESTERN NEBRASKA				
Dawes	234.7	35.4	28.7	15.1	12.2	27.3	62.7
Kimball	221.2	33.8	28.7	15.3	13.0	28.3	66.6
Average	227.9	34.6	28.7	15.2	12.6	27.8	64.6

Where grown	Number of stomata per sq. m. m.		Length of stoma		Length of epidermal cell		Width of epidermal cell	
	Upper epidermis	Lower epidermis	Upper epidermis	Lower epidermis	Upper epidermis	Lower epidermis	Upper epidermis	Lower epidermis
County (1)	(9)	(10)	*Microns* (11)	*Microns* (12)	*Microns* (13)	*Microns* (14)	*Microns* (15)	*Microns* (16)
				EASTERN NEBRASKA				
Richardson	69.9	86.2	49.2	47.5	96.7	87.3	35.7	37.4
Lancaster	68.5	84.0	50.6	48.7	107.4	97.7	35.5	35.1
Thurston	60.0	79.0	50.7	49.2	100.7	97.2	35.5	36.3
Average	66.1	83.0	50.2	48.4	101.6	94.1	35.6	36.3
				CENTRAL NEBRASKA				
Lincoln	73.2	95.9	50.1	48.3	83.9	71.4	36.1	35.5
Cherry	75.2	91.7	47.1	45.4	84.3	85.4	35.6	33.3
Average	74.2	93.8	48.6	46.8	84.1	78.4	35.8	34.4
				WESTERN NEBRASKA				
Dawes	74.3	89.4	44.0	45.9	84.6	79.8	36.4	35.9
Kimball	79.0	99.0	43.6	43.0	89.2	85.0	35.2	34.4
Average	76.6	94.2	43.8	44.4	86.9	82.4	35.8	35.1

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TABLE 13.—*Histological Leaf Measurements of Native Corn Types Grown in Various Regions of Nebraska. The Results for the Various Counties Are Here Expressed in Per Cent of the Results for Richardson County. 1915.*[1]

Where grown	Thickness of			Per cent of total leaf thickness of			Number vascular bundles per cm. leaf width
	Leaf	Upper epidermis	Lower epidermis	Upper epidermis	Lower epidermis	Total epidermis	
County (1)	*Microns* (2)	*Microns* (3)	*Microns* (4)	*Per cent* (5)	*Per cent* (6)	*Per cent* (7)	(8)
EASTERN NEBRASKA							
Richardson	100	100	100	100	100	100	100
Lancaster	94	97	91	102	97	100	107
Thurston	100	101	95	101	95	99	104
CENTRAL NEBRASKA							
Lincoln	103	98	96	95	93	94	94
Cherry	101	101	100	101	99	100	100
WESTERN NEBRASKA							
Dawes	102	101	97	99	95	97	98
Kimball	96	97	97	101	102	101	104

Where grown	Number of stomata per sq. m. m.		Length of stoma		Length of epidermal cell		Width of epidermal cell	
	Upper epidermis	Lower epidermis	Upper epidermis	Lower epidermis	Upper epidermis	Lower epidermis	Upper epidermis	Lower epidermis
County (1)	(9)	(10)	*Microns* (11)	*Microns* (12)	*Microns* (13)	*Microns* (14)	*Microns* (15)	*Microns* (16)
EASTERN NEBRASKA								
Richardson	100	100	100	100	100	100	100	100
Lancaster	98	97	103	102	111	112	99	94
Thurston	86	92	103	104	104	111	99	97
CENTRAL NEBRASKA								
Lincoln	105	111	102	102	87	82	101	95
Cherry	108	106	96	96	87	98	100	89
WESTERN NEBRASKA								
Dawes	106	104	89	97	87	91	102	96
Kimball	113	115	89	90	92	97	99	92

[1]Data calculated from Table 12.

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TABLE 14.—*Plant Characteristics of Native Corn Types Grown in Various Regions of Nebraska. 1915.*[1]

Where grown	Height of stalk	Height of ear	Leaf area	Total weight of plant	Weight of ear	Shelling per cent	Length of ear
County (1)	*Feet* (2)	*Feet* (3)	*Sq. in.* (4)	*Grams* (5)	*Grams* (6)	*Per cent* (7)	*Inches* (8)
			EASTERN NEBRASKA TYPES				
Richardson..	8.7	3.2	1,293	539	323	85	8.1
Lancaster....	8.3	4.3	1,222	416	195	84	7.0
Thurston....	7.7	2.9	1,048	322	165	80	7.0
Average.....	8.2	3.5	1,188	426	228	83	7.4
			CENTRAL NEBRASKA TYPES				
Lincoln.....	6.4	2.3	724	342	193	80	7.2
Cherry.....	6.3	2.0	692	244	116	75	6.1
Average.....	6.3	2.1	708	293	154	77	6.6
			WESTERN NEBRASKA TYPES				
Dawes.....	6.1	1.8	601	207	99	73	6.0
Kimball.....	5.2	1.1	470	185	79	71	5.3
Average.....	5.6	1.4	535	196	89	72	5.6

[1]A separate table is made for these seven counties in order that the summary data for the three larger regional sub-divisions may be entirely comparable with corresponding histological data of table 12, which includes only these seven rather than all twelve counties.

TABLE 15.—*Plant Characteristics of Native Corn Types Grown in Various Regions of Nebraska. The Results for the Various Counties Are Here Expressed in Per Cent of the Results for Richardson County. 1915.*[1]

Where grown	Height of stalk	Height of ear	Leaf area	Total weight of plant	Weight of ear	Shelling per cent	Length of ear
County (1)	*Per cent* (2)	*Per cent* (3)	*Per cent* (4)	*Per cent* (5)	*Per cent* (6)	*Per cent* (7)	*Per cent* (8)
			EASTERN NEBRASKA				
Richardson...	100	100	100	100	100	100	100
Lancaster.....	95	134	94	77	60	99	86
Thurston.....	88	91	81	60	51	94	86
			CENTRAL NEBRASKA				
Lincoln	74	72	56	63	60	94	89

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TABLE 16.—*Summary of Histological and Morphological Characteristics of Native Corn Types Grown in Various Regions of Nebraska. The Results for Central and Western Nebraska Are Here Expressed in Per Cent of the Results for Eastern Nebraska. 1915.*[1]

Region where grown	Thickness of			Per cent of total leaf thickness of			Number vascular bundles per cm. leaf width
	Leaf	Upper epidermis	Lower epidermis	Upper epidermis	Lower epidermis	Total epidermis	
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Eastern Nebraska	100	100	100	100	100	100	100
Central Nebraska	104	100	103	97	99	98	94
Western Nebraska	101	99	102	99	102	100	98

Region where grown	Number of stomata per sq. m. m.		Length of stoma		Length of epidermal cell		Width of epidermal cell	
	Upper epidermis	Lower epidermis	Upper epidermis	Lower epidermis	Upper epidermis	Lower epidermis	Upper epidermis	Lower epidermis
(1)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Eastern Nebraska	100	100	100	100	100	100	100	100
Central Nebraska	112	113	97	97	84	83	101	95
Western Nebraska	116	113	87	92	86	88	101	97

Region where grown	Height of stalk	Height of ear	Leaf area	Total weight of plant	Weight of ear	Shelling per cent	Length of ear
(1)	(17)	(18)	(19)	(20)	(21)	(22)	(24)
Eastern Nebraska.	100	100	100	100	100	100	100
Central Nebraska.	77	60	60	69	68	93	89
Western Nebraska	68	40	45	46	39	87	76

[1]Data calculated from Tables 12 and 14.

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significant histological adaptation. Practically speaking, the types adapted to the driest one-third of the State have developed no less succulent leaf, and no thicker epidermis resulting in reduced opportunity for water evaporation. The actual number of stomata per square millimeter is 14 per cent greater for western than for eastern Nebraska corn. This would seem to increase the opportunity for evaporation.

However, the greater number of stomata would seem to be offset by a reduction of 10 per cent in length. The fact that this 10 per cent reduction in length of stomata is accompanied by a 13 per cent reduction in length of the epidermal cell, which reduction would in no way be associated with water economy,

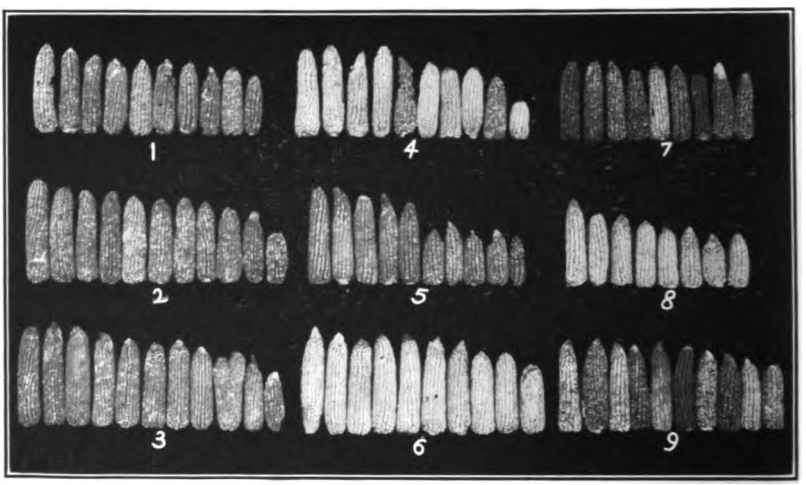

Fig. 12—Native corn types from nine regional areas of the state, grown comparably in southeastern Nebraska. (Lancaster County.)
Each group of ears is the harvest from ten successive representative plants of each type. The seed from all sources matured well when grown in Lancaster County.
(1) Thurston County corn, (2) Lancaster County corn, (3) Richardson County corn, (4) Holt County corn, (5) Kearney County corn, (6) Nuckolls County corn, (7) Cherry County corn, (8) Kimball County corn, (9) Lincoln County corn.

suggests that neither this stomatal shortening nor increased number of stomata per unit area are adaptive in nature. They are perhaps rather the combined result of less favorable growth conditions and of an inherent smaller cell development which is associated with the smaller plant growth habit of the earlier types.

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NATIVE CORN TYPES GROWN OUT OF THEIR HOME ENVIRONMENT

In these tests native seed corn was collected from each of the twelve localities within the State previously considered. These twelve lots of seed were distributed and grown comparatively in five of the same twelve localities, representing a wide range of conditions. Thus, in each test twelve types from various parts of the State were compared with each other in five different environments, one of the types in each case being native home-grown seed. Approximately 300 plants were grown from each type. Care was taken to eliminate the effects of variety plat competition by planting extra discard rows between unlike types.

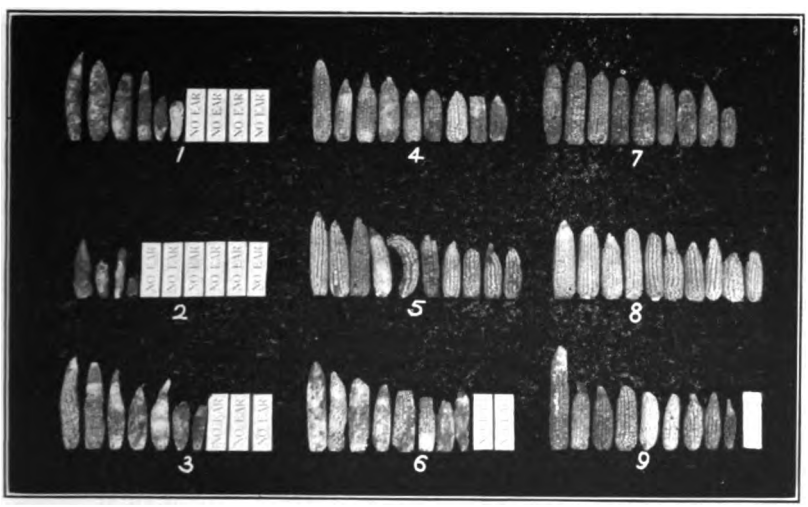

Fig. 13—Native corn types from nine regional areas of the state, grown comparably in extreme western Nebraska. (Kimball County.)
Each group of ears is the product of ten successive representative plants of each type. The native Kimball County type is the only one which fully matured when grown in Kimball County.
(1) Thurston County corn, (2) Lancaster County corn, (3) Richardson County corn, (4) Holt County corn, (5) Kearney County corn, (6) Nuckolls County corn, (7) Cherry County corn, (8) Kimball County corn, (9) Lincoln County corn.

Due perhaps in part to local seasonal abnormalities, and in part to the use of relatively few plants, a number of apparent inconsistencies occur. However, the nature of the data would seem to be such as to justify general conclusions.

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Morphological characters were recorded for all twelve types grown in each of the five tests. Histological measurements were made for the twelve types grown only in the most extreme regions, namely Lancaster County and Kimball County.

MORPHOLOGICAL CHARACTERS

The same general methods were employed and the same notes taken as in the previous investigation, (p. 22). The tabulated data for each type grown in each locality are the mean results for ten successive plants in a representative part of each plat. The detailed results are recorded in Tables 17 to 21, and are summarized in Tables 22 to 25. A careful study of the tables will show the relative growths made by (1) corn of the same source when grown in different regions, and (2) corn of different sources when grown in single locality.

In order to avoid a too tedious discussion, the reader is referred for most comparisons directly to the tables, and especially Tables 22 to 25. Only a few of the possible comparisons will be brought out in this discussion.

Native Lancaster County corn grew only 80 per cent as tall when grown in Kimball County as when grown in Lancaster County. Other relative values for Kimball County grown corn were: Height of ear, 52 per cent; leaf area, 78 per cent; stover weight, 62 per cent; ear weight, 1 per cent; total dry matter, 26 per cent; grain weight, 0.8 per cent; shelling percentage, 63; amount of leaf area per unit dry matter, 300 per cent; length of ear, 40 per cent; and ear circumference, 44 per cent. This illustrates the reduction in vegetative growth and even more extreme grain reduction when corn is moved to a less favorable region.

On the other hand, when corn is moved to a more favorable region, its vegetative growth and grain production are considerably increased. To illustrate, when native Kimball County corn was grown both at home and in Lancaster County the ratios of the latter to the former were: Plant height, 129 per cent; ear height, 154 per cent; leaf area, 140 per cent; stover weight, 161 per cent; ear weight, 135 per cent; total dry matter, 146

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...t Characteristics of Corn Types When Moved from Their Various Native ...alities and Grown in Southeastern Nebraska. (Lancaster County) 1916.

...measurements		Dry matter				Shelling per cent	Leaf area per gram dry matter	Ear measurements		Kernel measurements		
Height of ear	Leaf area	Stover	Ear	Total	Grain			Length	Circumference	Length	Width	Weight
Feet (3)	*Sq. In.* (4)	*Grams* (5)	*Grams* (6)	*Grams* (7)	*Grams* (8)	*Per cent* (9)	*Sq. In.* (10)	*Inches* (11)	*Inches* (12)	*Inches* (13)	*Inches* (14)	*Grams* (15)
EASTERN NEBRASKA TYPES												
4.2	1,298	220	286	506	249	87	2.6	7.8	5.9	.50	.27	.276
4.2	1,414	193	276	469	240	87	3.0	7.8	6.4	.51	.28	.289
4.3	1,407	215	209	424	176	85	3.5	7.4	6.2	.48	.28	.280
3.3	1,209	174	197	371	165	84	3.2	7.0	6.1	.47	.31	.280
3.4	1,459	217	283	500	229	81	2.9	8.1	6.8	.48	.33	.347
3.9	1,357	204	250	454	212	85	3.0	7.6	6.3	.49	.29	.294
CENTRAL NEBRASKA TYPES												
3.5	1,259	185	179	364	149	83	3.4	6.7	6.0	.48	.33	.331
3.2	1,219	202	196	398	153	78	3.0	7.0	6.3	.46	.33	.314
3.1	849	167	197	364	160	81	2.2	7.4	5.8	.45	.35	.316
2.8	833	155	166	321	131	79	2.6	6.4	5.9	.43	.33	.327
3.1	1,040	177	184	361	148	80	2.8	6.9	6.0	.45	.33	.344
WESTERN NEBRASKA TYPES												
1.7	594	108	123	231	96	78	2.6	6.2	5.8	.43	.34	.307
2.0	775	161	157	318	129	82	2.4	6.7	5.6	.45	.34	.293
1.8	684	134	140	274	112	80	2.5	6.4	5.7	.44	.34	.300

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: *Characteristics of Corn Types When Moved from Their Various Native alities and Grown in Northeastern Nebraska. (Thurston County) 1916.*

measurements		Dry matter				Shelling per cent	Leaf area per gram dry matter	Ear measurements		Kernel measurements		
Height of ear	Leaf area	Stover	Ear	Total	Grain			Length	Circumference	Length	Width	Weight
Feet (3)	*Sq. In.* (4)	*Grams* (5)	*Grams* (6)	*Grams* (7)	*Grams* (8)	*Per cent* (9)	*Sq. In.* (10)	*Inches* (11)	*Inches* (12)	*Inches* (13)	*Inches* (14)	*Grams* (15)
EASTERN NEBRASKA TYPES												
4.4	1,502	184	175	359	147	84	4.2	7.5	5.9	.45	.27	.205
4.4	1,320	208	171	379	145	85	3.5	6.5	6.0	.48	.29	.237
4.6	1,596	233	133	366	112	84	4.4	6.3	4.8	.48	.28	.251
3.5	985	169	152	321	125	82	3.1	5.8	5.5	.44	.29	.245
4.5	1,330	200	140	340	115	82	3.9	6.0	5.7	.46	.32	.267
4.3	1,346	199	154	353	129	83	3.8	6.4	5.6	.46	.29	.241
CENTRAL NEBRASKA TYPES												
3.4	1,086	142	146	288	128	88	3.8	5.8	5.6	.46	.30	.280
3.2	1,081	158	144	302	122	85	3.6	5.5	5.8	.48	.31	.279
3.2	939	151	119	270	100	84	3.5	5.2	5.3	.43	.33	.307
3.0	936	119	135	254	115	85	3.7	5.5	5.1	.43	.33	.295
3.2	1,010	142	136	278	116	85	3.6	5.5	5.4	.45	.32	.290
WESTERN NEBRASKA TYPES												
2.3	647	111	125	236	101	81	2.7	5.4	5.6	.42	.36	.326
2.4	808	104	143	247	117	82	3.3	5.9	5.7	.43	.34	.296
2.3	717	91	113	204	95	84	3.5	5.5	5.4	.41	.32	.260
2.3	724	102	127	229	104	82	3.2	5.6	5.6	.42	.34	.294

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nt Characteristics of Corn Types When Moved from Their Various Native Localities and Grown in North-central Nebraska. (Cherry County) 1916.

nt measurements		Dry matter				Shelling per cent	Leaf area per gram dry matter	Ear measurements		Kernel measurements		
t Height of ear	Leaf area	Stover	Ear	Total	Grain			Length	Circumference	Length	Width	Weight
Feet (3)	*Sq. In.* (4)	*Grams* (5)	*Grams* (6)	*Grams* (7)	*Grams* (8)	*Per cent* (9)	*Sq. In.* (10)	*Inches* (11)	*Inches* (12)	*Inches* (13)	*Inches* (14)	*Grams* (15)
EASTERN NEBRASKA TYPES												
2.6	1,094	167	143	310	113	79	3.5	6.9	5.7	.41	.25	.126
2.9	959	165	130	295	94	72	3.2	6.7	5.6	.40	.25	.085
2.7	991	163	123	286	89	72	3.5	7.9	5.5	.40	.27	.126
2.2	891	145	163	308	130	80	2.9	7.2	5.8	.44	.30	.175
3.1	1,066	185	141	326	109	77	3.2	7.5	6.0	.43	.30	.157
2.7	1,000	165	140	305	107	76	3.3	7.2	5.7	.42	.27	.134
CENTRAL NEBRASKA TYPES												
2.0	820	156	94	250	64	68	3.3	7.3	5.5	.41	.31	.176
2.1	954	153	149	302	119	80	3.1	6.4	5.8	.44	.32	.214
2.1	840	143	146	289	112	77	2.9	7.6	5.8	.42	.32	.215
1.7	624	121	151	272	121	80	2.2	7.3	5.5	.41	.32	.209
2.0	809	143	135	278	104	76	2.8	7.1	5.6	.42	.32	.203
WESTERN NEBRASKA TYPES												
1.0	376	70	109	179	88	81	2.0	6.2	5.8	.41	.31	.216
1.3	587	106	142	248	112	79	2.3	6.1	5.8	.32	.43	.224
1.1	440	65	131	196	110	84	2.2	5.5	5.3	.41	.32	.276
1.1	468	80	127	207	103	81	3.3	5.9	5.6	.38	.35	.239

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Characteristics of Corn Types When Moved from Their Various Native calities and Grown in West-central Nebraska. (Lincoln County) 1916.

easurements		Dry matter				Shelling per cent	Leaf area per gram dry matter	Ear measurements		Kernel measurements		
eight of ear	Leaf area	Stover	Ear	Total	Grain			Length	Circum-ference	Length	Width	Weight
Feet (3)	*Sq. In.* (4)	*Grams* (5)	*Grams* (6)	*Grams* (7)	*Grams* (8)	*Per cent* (9)	*Sq. In.* (10)	*Inches* (11)	*Inches* (12)	*Inches* (13)	*Inches* (14)	*Grams* (15)
					EASTERN NEBRASKA TYPES							
2.7	1,074	128	68	197	57	84	5.4	5.6	5.3	.42	.27	.201
2.4	1,061	133	75	208	62	83	5.1	5.4	5.1	.45	.29	.228
2.8	1,150	150	47	197	39	83	5.8	3.8	4.9	.46	.29	.246
2.1	941	142	64	206	51	80	4.6	4.2	4.9	.41	.27	.225
2.0	1,002	130	98	228	76	78	4.4	5.6	5.3	.45	.30	.282
2.4	1,046	137	70	207	57	82	5.1	4.9	5.1	.44	.28	.236
					CENTRAL NEBRASKA TYPES							
1.8	836	111	110	221	89	81	3.8	6.4	5.5	.46	.33	.392
1.6	922	105	45	150	36	81	6.1	4.9	5.2	.41	.32	.273
1.7	792	118	119	237	92	77	3.3	5.7	5.1	.43	.31	.266
1.4	762	108	76	184	62	81	4.1	5.2	4.6	.41	.33	.264
1.6	828	110	87	197	70	80	4.4	5.5	5.1	.43	.32	.299
					WESTERN NEBRASKA TYPES							
1.2	472	73	62	135	50	80	3.4	5.0	5.0	.40	.35	.308
1.3	563	105	54	159	42	78	3.5	4.4	4.8	.39	.33	.278
1.1	525	74	58	132	46	79	4.0	4.1	4.9	.41	.34	.288
1.2	520	84	58	147	46	79	3.6	4.5	4.9	.40	.34	.291

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nt Characteristics of Corn Types When Moved from Their Various Native Localities and Grown in Extreme Western Nebraska. (Kimball County) 1916.

t measurements		Dry matter				Shelling per cent	Leaf area per gram dry matter	Ear measurements[1]		Kernel measurements		
Height of ear	Leaf area	Stover	Ear	Total	Grain			Length	Circumference	Length	Width	Weight
Feet (3)	*Sq. In.* (4)	*Grams* (5)	*Grams* (6)	*Grams* (7)	*Grams* (8)	*Per cent* (9)	*Sq. In.* (10)	*Inches* (11)	*Inches* (12)	*Inches* (13)	*Inches* (14)	*Grams* (15)
EASTERN NEBRASKA TYPES												
3.0	1,050	128	24	152	18	74	6.9	5.8	3.2	.35	.23	.059
2.2	1,100	119	3	122	2	55	9.0	3.1	2.8	.....	.....	.....
3.0	1,140	143	17	160	7	41	7.1	6.0	4.8	.34	.25	.082
3.1	563	100	22	122	15	70	4.6	6.3	4.4	.28	.22	.081
2.0	1,042	156	36	192	28	77	5.4	6.1	5.1	.35	.28	.081
2.7	979	129	20	149	14	63	6.6	5.5	4.1	.26[2]	.24[2]	.076[2]
CENTRAL NEBRASKA TYPES												
1.9	718	102	70	172	54	77	4.2	5.5	5.1	.36	.28	.116
1.9	759	108	49	157	33	68	4.9	5.5	5.3	.32	.27	.099
1.6	491	76	55	131	40	73	3.7	5.3	4.9	.34	.28	.124
1.4	536	73	79	152	62	78	3.5	5.4	5.2	.36	.29	.148
1.7	626	90	63	153	47	74	3.9	5.4	5.1	.34	.28	.122
WESTERN NEBRASKA TYPES												
1.1	425	67	91	158	73	80	2.7	5.5	5.4	.39	.30	.197
1.6	426	77	53	130	37	70	3.3	4.2	4.4	.34	.25	.174
1.0	330	65	76	141	56	74	2.3	4.5	4.7	.35	.28	.144
1.2	394	70	73	143	55	75	2.8	4.7	4.8	.36	.28	.172

ments in this and similar tables are the average for the ears produced, whereas, the ear and t is the mean for the entire number of plants.
four counties only.

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*ary of Plant Characteristics of Corn Types When Moved from Their tive Nebraska Localities and Interchanged with Each Other. 1916.**

easurements		Dry matter				Shelling per cent	Leaf area per gram dry matter	Ear measurements		Kernel measurements		
ight of ar	Leaf area	Stover	Ear	Total	Grain			Length	Circumference	Length	Width	Weight
'eet 3)	*Sq. In.* (4)	*Grams* (5)	*Grams* (6)	*Grams* (7)	*Grams* (8)	*Per cent* (9)	*Sq. In.* (10)	*Inches* (11)	*Inches* (12)	*Inches* (13)	*Inches* (14)	*Grams* (15)
NATIVE LANCASTER COUNTY CORN												
.2	1,414	193	276	469	240	87	3.0	7.8	6.4	.51	.28	.289
.4	1,320	208	171	379	145	85	3.5	6.5	6.0	.48	.29	.237
.4	1,061	133	75	208	62	83	5.1	5.4	5.1	.45	.29	.228
.9	959	165	130	295	94	72	3.2	6.7	5.6	.40	.25	.085
.2	1,100	119	3	122	2	55	9.0	3.1	2.8			
NATIVE THURSTON COUNTY CORN												
.3	1,209	174	197	371	165	84	3.2	7.0	6.1	.47	.31	.280
.5	985	169	152	321	125	82	3.1	5.8	5.5	.44	.29	.245
.1	941	142	64	206	51	80	4.6	4.2	4.9	.41	.27	.225
.2	891	145	163	308	130	80	2.9	7.2	5.8	.44	.30	.175
.1	563	100	22	122	15	70	4.6	6.3	4.4	.28	.22	.081
NATIVE LINCOLN COUNTY CORN												
.1	849	167	197	364	160	81	2.2	7.4	5.8	.45	.35	.316
.2	939	151	119	270	100	84	3.5	5.2	5.3	.43	.33	.307
.7	792	118	119	237	92	77	3.3	5.7	5.1	.43	.31	.266
.1	840	143	146	289	112	77	2.9	7.6	5.8	.42	.32	.215
.6	491	76	55	131	40	73	3.7	5.3	4.9	.34	.28	.124
NATIVE CHERRY COUNTY CORN												
.8	833	155	166	321	131	79	2.6	6.4	5.9	.43	.33	.327
.0	936	119	135	254	115	85	3.7	5.5	5.1	.43	.33	.295
.4	762	108	76	184	62	81	4.1	5.2	4.6	.41	.33	.264
.7	624	121	151	272	121	80	2.2	7.3	5.5	.41	.32	.209
.4	536	73	79	152	62	78	3.5	5.4	5.2	.36	.29	.148
NATIVE KIMBALL COUNTY CORN												
.7	594	108	123	231	96	78	2.6	6.2	5.8	.43	.34	.307
.3	647	111	125	236	101	81	2.7	5.4	5.6	.42	.36	.326
.2	472	73	62	135	50	80	3.4	5.0	5.0	.40	.35	.308
.0	376	70	109	179	88	81	2.0	6.2	5.8	.41	.31	.216
.1	425	67	91	158	73	80	2.7	5.5	5.4	.39	.30	.197

ibles 17 to 21.

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E 23.—*Summary of Plant Characteristics of Corn Types When Moved from Their arious Native Nebraska Localities and Interchanged with Each Other. For Each ative Type the Native Home-Grown Crop is Regarded as 100 Per Cent. 1916.**

rown	Plant measurements			Dry matter				Shelling per cent	Leaf area per gram dry matter	Ear measurements		Kernel measurements		
	Height of stalk	Height of ear	Leaf area	Stover	Ear	Total	Grain			Length	Circumference	Length	Width	Weight
y	Percent (2)	Percent (3)	Per cent (4)	Per cent (5)	Per cent (6)	Per cent (7)	Per cent (8)	Per cent (9)	Per cent (10)	Per cent (11)	Per cent (12)	Per cent (13)	Per cent (14)	Per cent (15)
NATIVE LANCASTER COUNTY CORN														
.....	100	100	100	100	100	100	100	100	100	100	100	100	100	100
.....	112	105	93	108	62	81	60	98	117	83	94	94	104	82
.....	76	57	75	69	27	44	26	95	170	69	80	88	104	79
.....	95	69	68	85	47	63	39	83	106	86	87	78	89	29
.....	80	52	78	62	1	26	0.8	63	300	40	44	.....	.....	.....
NATIVE THURSTON COUNTY CORN														
.....	100	100	100	100	100	100	100	100	100	100	100	100	100	100
.....	95	94	123	103	130	115	132	102	103	121	111	107	107	114
.....	70	60	95	84	42	64	41	98	149	72	89	93	93	92
.....	87	63	90	86	107	96	104	98	94	124	105	100	103	71
.....	70	89	57	60	14	38	12	85	149	109	80	64	76	33
NATIVE LINCOLN COUNTY CORN														
.....	100	100	100	100	100	100	100	100	100	100	100	100	100	100
.....	120	182	107	141	165	154	174	105	66	130	114	105	113	119
.....	149	188	119	128	100	114	109	109	106	91	104	100	106	115
.....	125	123	106	121	123	122	122	100	88	133	114	98	103	81
.....	100	94	62	64	44	55	43	95	112	93	96	79	90	47
NATIVE CHERRY COUNTY CORN														
.....	100	100	100	100	100	100	100	100	100	100	100	100	100	100
.....	103	165	133	128	110	118	108	99	111	88	107	105	103	156
.....	122	176	150	98	89	93	95	106	168	75	93	105	103	141
.....	81	82	122	89	50	68	51	101	186	71	84	100	103	126
.....	84	82	.86	60	52	56	51	97	159	74	94	88	91	71
NATIVE KIMBALL COUNTY CORN														
.....	100	100	100	100	100	100	100	100	100	100	100	100	100	100
.....	129	154	140	161	135	146	131	97	96	113	107	110	113	156
.....	152	209	152	166	137	149	138	101	100	98	104	108	120	165
.....	100	109	111	109	68	85	68	100	126	91	93	103	117	156
.....	112	91	88	104	120	113	120	101	74	113	107	105	103	110

*Compiled from data in Table 22

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mmary of Plant Characteristics of Corn Types When Moved from Their s Native Nebraska Localities and Grown in Different Regions. 1916.

ant measurements			Dry matter				Shelling per cent	Leaf area per gram dry matter	Ear measurements		Kernel measurements		
ht	Height of ear	Leaf area	Stover	Ear	Total	Grain			Length	Circumference	Length	Width	Weight
	Feet (3)	*Sq. In.* (4)	*Grams* (5)	*Grams* (6)	*Grams* (7)	*Grams* (8)	*Per cent* (9)	*Sq. In.* (10)	*Inches* (11)	*Inches* (12)	*Inches* (13)	*Inches* (14)	*Grams* (15)
EASTERN NEBRASKA TYPES													
	3.9	1,357	204	250	454	212	85	3.0	7.6	6.3	.49	.29	.294
	4.3	1,347	199	154	353	129	83	3.8	6.4	5.6	.46	.29	.241
	2.4	1,046	137	70	207	57	82	5.1	4.9	5.1	.44	.28	.236
	2.7	1,000	165	140	305	107	76	3.2	7.2	5.7	.42	.27	.134
	2.7	979	129	20	150	14	63	6.6	5.5	4.1	.26	.24	.076
CENTRAL NEBRASKA TYPES													
	3.1	1,040	177	184	361	148	80	2.7	6.9	6.0	.45	.33	.344
	3.2	1,010	142	136	278	116	85	3.6	5.5	5.4	.45	.32	.290
	1.6	828	110	87	197	70	80	4.4	5.5	5.1	.43	.32	.299
	2.0	809	143	135	278	104	76	2.8	7.1	5.6	.42	.32	.203
	1.7	626	90	63	153	47	74	3.9	5.4	5.1	.34	.28	.122
WESTERN NEBRASKA TYPES													
	1.8	684	134	140	274	112	80	2.5	6.4	5.7	.44	.34	.300
	2.3	724	102	127	228	104	82	3.2	5.6	5.6	.42	.34	.274
	1.2	520	84	58	147	46	79	3.6	4.5	4.9	.40	.34	.290
	1.1	468	80	127	208	103	81	3.3	5.9	5.6	.38	.35	.239
	1.2	394	70	73	143	55	75	2.8	4.7	4.8	.36	.28	.172

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nmary of Plant Characteristics of Corn Types When Moved from Their tive Nebraska Localities and Grown in Different Regions. Data Are Based on n in Lancaster County as 100 Per Cent.

measurements		Dry matter				Shelling per cent	Leaf area per gram dry matter	Ear measurements		Kernel measurements		
Height of ear	Leaf area	Stover	Ear	Total	Grain			Length	Circumference	Length	Width	Weight
Per cent (3)	*Per cent* (4)	*Per cent* (5)	*Per cent* (6)	*Per cent* (7)	*Per cent* (8)	*Per cent* (9)	*Per cent* (10)	*Per cent* (11)	*Per cent* (12)	*Per cent* (13)	*Per cent* (14)	*Per cent* (15)
EASTERN NEBRASKA TYPES												
100	100	100	100	100	100	100	100	100	100	100	100	100
110	99	98	62	78	61	98	127	84	89	94	100	82
61	77	67	28	46	27	96	170	64	81	90	97	81
69	74	81	56	67	50	89	107	95	90	86	93	46
69	72	63	8	33	7	74	220	72	65	53	83	26
CENTRAL NEBRASKA TYPES												
100	100	100	100	100	100	100	100	100	100	100	100	100
103	97	80	74	77	78	106	133	80	90	100	97	84
52	80	62	47	55	47	100	163	80	85	96	97	87
64	78	81	73	77	70	95	104	103	93	93	97	59
55	60	51	34	42	32	92	144	78	85	76	85	35
WESTERN NEBRASKA TYPES												
100	100	100	100	100	100	100	100	100	100	100	100	100
128	106	76	91	83	93	102	128	87	98	95	100	91
67	76	63	41	54	41	99	144	70	86	91	100	97
61	68	60	91	76	92	101	132	92	98	86	103	80
67	58	52	52	52	49	94	112	73	84	82	82	57

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grain weight, 100 and 30; shelling percentage, 100 and 92; amount of leaf area per unit dry matter, 100 and 90; ear length, 100 and 70; and ear circumference, 100 and 84.

When native Lancaster County corn was grown in Lancaster, Thurston, Cherry, Lincoln, and Kimball Counties, the respective relative total plant weights were: 100, 81, 63, 44, and 26, while the respective relative grain weights were: 100, 60, 39, 26, and 0.8.

When native Kimball County corn was planted in Kimball, Lincoln, Cherry, Thurston, and Lancaster Counties, the relative total plant weights were respectively: 100, 85, 113, 149, and 146. Corresponding relative grain values were: 100, 68, 120, 138, and 131.

In less extreme cases than the above comparisons, less marked growth differences usually exist, and great regularity and consistency did not always prevail. In the main, however, indications are similar.

In Table 24 the twelve native corn types which were planted in five different parts of the State are assembled regionally. Thus, we have three groups—eastern, central, and western Nebraska types, grown comparatively in Lancaster, Thurston, Cherry, Lincoln, and Kimball Counties. In Table 25 relative values are given for each group, based on the mean results for the corn grown in Lancaster County.

The relative total yields of dry matter for eastern Nebraska types grown in Lancaster, Thurston, Cherry, Lincoln and Kimball Counties were respectively: 100, 78, 67, 46, and 33. Corresponding relative yields of grain per plant were: 100, 61, 50, 27 and 7.

The relative total yields of dry matter for central Nebraska types grown in Lancaster, Thurston, Cherry, Lincoln, and Kimball Counties were respectively: 100, 77, 77, 55, and 42. Corresponding yields of grain were: 100, 78, 70, 47, and 32.

The relative total yields of dry matter for western Nebraska types grown in Lancaster, Thurston, Cherry, Lincoln, and Kimball Counties were respectively: 100, 83, 76, 54, and 52. Corresponding grain yields were: 100, 93, 92, 41, and 49.

The effects of interchanging native corn types upon their relative development may be similarly observed for other plant characters by a study of the tables.

HISTOLOGICAL LEAF CHARACTERS

The eleven native types considered morphologically in the preceding discussion, were also compared as to leaf structure when grown in both Lancaster and Kimball Counties. These

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represent extreme conditions, and it is believed that by such comparison, structural differences due either to hereditary adaptation or to mere environmental adjustment, may be determined. (Tables 26-28.) The methods of sampling and technique were the same as previously described. Seven hundred and twenty transectional leaf measurements, and one thousand epidermal counts and measurements were made for each of the eleven corn types grown in Lancaster and Kimball Counties, respectively.

Comparing eastern, central, and western Nebraska types when grown in Lancaster County we have the following relative leaf values: (1) Leaf thickness, 100, 103, and 104; (2) average epidermal thickness, 100, 100, and 103; (3) thickness of cuticle, 100, 101, and 98; (4) number of vascular bundles per unit of cross section, 100, 95, and 100; (5) number of stomata per unit area of epidermis, 100, 101, 97; (6) length of stoma, 100, 100, and 100; (7) length of stomatal aperture, 100, 94, and 90; (8) length of epidermal cell, 100, 93, and 94; and (9) width of epidermal cell, 100, 100, and 104.

Corresponding relative values for corn grown in Kimball County were: (1) Leaf thickness, 100, 89, and 95; (2) average epidermal thickness, 100, 97, and 96; (3) thickness of cuticle, 100, 98, and 98; (4) number of vascular bundles per unit of cross section, 100, 103, and 101; (5) number of stomata per unit area of epidermis, 100, 104, and 102; (6) length of stomata, 100, 101, and 98; (7) length of stomatal aperture, 100, 101, and 96; (8) length of epidermal cell, 100, 100, and 100; and (9) width of epidermal cell, 100, 95, and 100.

As an average for corn grown in both Lancaster and Kimball Counties the respective relative values for eastern, central, and western Nebraska types were: (1) Leaf thickness, 100, 96, and 100; (2) average epidermal thickness, 100, 99, and 100; (3) thickness of cuticle, 100, 100, 98; (4) number of vascular bundles per unit cross section of leaf, 100, 99, and 100; (5) number of stomata per unit area of epidermis, 100, 102, and 99; (6) length of stomata, 100, 100, and 99; (7) length of stomatal aperture, 100, 97, and 93; (8) length of epidermal cell, 100, 97, and 97; and (9) width of epidermal cell, 100, 97, and 102.

To determine the effect of the environment only upon the corn leaf structure, we may compare the mean results of the twelve types grown in Lancaster County as against the same corn grown in Kimball County. The relative values based on Lancaster County as 100 per cent are: (1) Leaf thickness, 100 and 87; (2) average epidermal thickness, 100 and 91; (3) thickness of cuticle, 100 and 97; (4) number of vascular bundles

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gical Leaf Measurements of Corn Types When Moved from Their Various ka Localities and Grown in Southeastern Nebraska. (Lancaster County)

Thickness of			Per cent of total leaf thickness of			Thickness of cuticle of			Per cent of epidermal thickness of			Number vascular bundles per cm. leaf width
af	Upper epidermis	Lower epidermis	Upper epidermis	Lower epidermis	Total epidermis	Upper epidermis	Lower epidermis	Total cuticle	Upper cuticle	Lower cuticle	Total cuticle	
ons	*Microns* (3)	*Microns* (4)	*Per cent* (5)	*Per cent* (6)	*Per cent* (7)	*Microns* (8)	*Microns* (9)	*Microns* (10)	*Per cent* (11)	*Per cent* (12)	*Per cent* (13)	(14)
EASTERN NEBRASKA TYPES												
.0	33.8	27.0	15.3	12.2	27.5	5.8	4.9	10.7	17.1	18.1	17.6	69.2
.8	35.1	29.2	15.8	13.1	28.9	6.5	5.9	12.4	18.5	20.2	19.3	68.6
.8	33.4	25.9	15.9	12.3	28.2	6.4	5.6	12.0	19.1	21.6	20.3	70.1
.2	36.3	29.0	16.1	12.8	28.9	6.6	6.2	12.8	18.1	21.3	19.7	66.5
.2	34.3	28.6	15.6	13.0	28.5	6.8	6.3	13.1	19.8	22.0	20.9	66.7
.2	34.6	27.9	15.7	12.7	28.4	6.4	5.8	12.2	18.5	20.6	19.6	68.2
CENTRAL NEBRASKA TYPES												
.9	35.3	29.5	15.4	12.9	28.2	6.4	5.9	12.3	18.1	20.0	19.0	64.4
.5	32.9	27.1	14.6	12.0	26.6	6.6	6.2	12.8	20.0	22.8	21.4	68.7
.2	35.1	28.4	15.4	12.4	27.7	6.2	5.6	11.8	17.6	19.7	18.6	60.5
.1	34.6	28.1	15.5	12.6	28.1	6.5	6.1	12.6	18.7	21.7	20.2	66.8
.9	34.5	28.3	15.2	12.4	27.6	6.4	5.9	12.3	18.6	21.1	19.8	65.1
WESTERN NEBRASKA TYPES												
.0	34.2	27.6	15.2	12.3	27.5	5.9	5.1	11.0	17.2	18.4	17.8	68.6
.5	36.9	30.4	15.9	13.0	28.8	6.9	6.1	13.0	18.7	20.0	19.3	68.1
.2	35.5	29.0	15.5	12.6	28.1	6.4	5.6	12.0	17.9	19.2	18.5	68.3

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e 26 (continued).—*Histological Leaf Measurements of Corn Types When Moved from Their Various Native Nebraska Localities and Grown in Southeastern Nebraska. (Lancaster County) 1916.*

rce of seed	Number of stomata per sq. m. m.			Length of stoma			Length of stomatal aperture			Length of epidermal cell		Width of epidermal cell	
	Upper epidermis	Lower epidermis	Average	Upper epidermis	Lower epidermis	Average	Upper epidermis	Lower epidermis	Average	Upper epidermis	Lower epidermis	Upper epidermis	Lower epidermis
'ounty (1)	(2)	(3)	(4)	*Microns* (5)	*Microns* (6)	*Microns* (7)	*Microns* (8)	*Microns* (9)	*Microns* (10)	*Microns* (11)	*Microns* (12)	*Microns* (13)	*Microns* (14)
EASTERN NEBRASKA TYPES													
lson	76.9	90.5	83.7	48.3	48.1	48.2	16.7	16.4	16.5	87.2	86.4	33.1	33.9
:er	80.2	102.7	91.4	49.5	48.5	49.0	17.0	16.6	16.8	83.2	83.5	34.5	34.0
gton	81.5	95.9	88.7	50.5	47.0	48.7	17.7	17.6	17.6	88.5	91.9	34.1	34.5
)n	79.1	93.0	86.0	50.9	50.2	50.5	16.9	16.8	16.8	81.7	81.6	32.7	34.2
ls	75.6	91.1	83.3	51.6	51.9	51.7	17.8	18.0	17.9	81.8	79.2	34.6	33.7
age	78.7	94.6	86.6	50.2	49.1	49.6	17.2	17.1	17.1	84.5	84.5	33.8	34.1
CENTRAL NEBRASKA TYPES													
y	68.2	82.2	75.2	51.3	49.3	50.3	17.9	17.1	17.5	82.5	80.4	35.0	34.2
	91.0	115.9	103.4	47.6	46.7	47.1	15.6	15.5	15.5	77.5	77.2	31.4	31.9
	79.8	81.6	80.7	50.7	53.3	52.0	14.3	16.1	15.7	77.9	79.0	34.5	36.7
	78.6	103.5	91.0	51.1	47.7	49.4	15.3	15.4	15.3	77.7	77.8	34.2	33.1
age	79.4	95.8	87.6	50.2	49.2	49.7	16.0	16.0	16.0	78.9	78.6	33.8	34.0
WESTERN NEBRASKA TYPES													
ll	79.3	94.8	87.0	48.8	49.4	49.1	15.2	15.7	15.4	78.6	83.6	34.4	34.8
	72.6	91.3	81.9	51.5	49.2	50.3	15.1	15.5	15.3	78.2	77.9	36.2	35.8
age	75.9	93.0	84.4	50.1	49.3	49.7	15.1	15.6	15.3	78.4	80.7	35.3	35.3

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27.—*Histological Leaf Measurements of Corn Types When Moved from Their Various tive Nebraska Localities and Grown in Extreme Western Nebraska. (Kimball County) 16.*

e of seed	Thickness of			Per cent of total leaf thickness of			Thickness of cuticle of			Per cent of epidermal thickness of			Number vascular bundles per cm. leaf width
	Leaf	Upper epidermis	Lower epidermis	Upper epidermis	Lower epidermis	Total epidermis	Upper epidermis	Lower epidermis	Total cuticle	Upper cuticle	Lower cuticle	Total cuticle	
unty (1)	*Microns* (2)	*Microns* (3)	*Microns* (4)	*Per cent* (5)	*Per cent* (6)	*Per cent* (7)	*Microns* (8)	*Microns* (9)	*Microns* (10)	*Per cent* (11)	*Per cent* (12)	*Per cent* (13)	(14)
EASTERN NEBRASKA TYPES													
on	202.6	30.5	25.3	15.0	12.4	27.4	6.3	5.9	12.2	20.6	23.3	21.9	78.3
er	222.0	33.6	27.2	15.1	12.2	27.3	6.6	6.2	12.8	19.6	22.8	21.2	79.7
ton	204.1	30.9	25.9	15.1	12.7	27.7	5.8	5.5	11.3	18.7	21.2	19.9	67.9
n	197.5	31.8	26.7	16.1	13.5	29.6	5.6	5.6	11.2	17.6	20.9	19.2	78.9
	195.3	32.1	28.5	16.4	14.6	31.0	6.3	6.0	12.3	19.6	21.0	20.3	77.3
ge	204.3	31.8	26.7	15.5	13.1	28.6	6.1	5.8	12.0	19.2	21.8	20.5	76.4
CENTRAL NEBRASKA TYPES													
	176.2	31.2	26.0	17.7	14.7	32.4	6.5	6.1	12.6	20.8	23.4	22.1	79.4
	198.2	32.0	26.2	16.1	13.2	29.3	6.3	6.0	12.3	19.7	22.9	21.3	74.8
	182.6	30.1	26.6	16.4	14.5	30.9	6.0	5.8	11.8	19.9	21.8	20.8	77.6
	172.3	29.2	25.0	16.9	14.5	31.4	5.4	5.0	10.4	18.4	20.0	19.2	82.7
ge	182.3	30.6	25.9	16.8	14.2	31.0	6.0	5.7	11.8	19.7	22.0	20.8	78.6
WESTERN NEBRASKA TYPES													
	204.7	32.0	26.3	15.6	12.8	28.4	6.3	5.8	12.1	19.7	22.0	20.8	71.3
	184.5	28.5	25.2	15.4	13.6	29.0	5.9	5.6	11.5	20.7	22.2	21.4	82.6
ge	194.6	30.2	25.7	15.5	13.2	28.7	6.1	5.7	11.8	20.2	22.1	21.0	76.9

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27 (continued).—*Histological Measurements of Corn Types When Moved from Their arious Native Nebraska Localities and Grown in Extreme Western Nebraska. (Kim- ll County) 1916.*

e of orn	Number of stomata per sq. m. m.			Length of stoma			Length of stomatal aperture			Length of epidermal cell		Width of epidermal cell	
	Upper epidermis	Lower epidermis	Average	Upper epidermis	Lower epidermis	Average	Upper epidermis	Lower epidermis	Average	Upper epidermis	Lower epidermis	Upper epidermis	Lower epidermis
unty (1)	(15)	(16)	(17)	*Microns* (18)	*Microns* (19)	*Microns* (20)	*Microns* (21)	*Microns* (22)	*Microns* (23)	*Microns* (24)	*Microns* (25)	*Microns* (26)	*Microns* (27)
EASTERN NEBRASKA TYPES													
ion.....	84.5	93.7	89.1	43.4	45.8	44.6	10.8	13.7	12.2	75.3	79.0	32.0	32.8
er.....	85.4	109.4	97.4	48.2	47.4	47.8	15.3	15.2	15.2	80.7	78.1	32.5	32.1
ton.....	74.2	94.9	84.5	47.3	47.1	47.2	14.4	14.8	14.6	83.2	80.0	31.8	34.6
n.....	81.3	107.3	94.3	47.8	45.2	46.5	14.6	13.9	14.2	81.0	78.4	31.7	30.8
.....	74.8	89.9	82.3	50.8	49.0	49.9	16.5	15.6	16.0	80.7	79.0	32.1	32.1
ge.....	80.0	99.0	89.5	47.5	46.9	47.2	14.3	14.6	14.4	80.2	78.9	32.0	32.5
CENTRAL NEBRASKA TYPES													
.....	83.0	84.2	83.6	48.2	49.9	49.0	14.7	16.0	15.3	79.0	81.1	29.9	30.8
.....	68.5	108.8	88.6	50.3	49.5	49.9	16.0	16.0	16.0	81.1	82.0	33.0	29.1
.....	79.8	109.4	94.6	48.6	46.4	47.5	14.3	14.3	14.3	80.3	80.7	31.7	29.9
.....	94.5	115.1	104.8	43.7	43.3	43.5	12.8	12.7	12.7	76.9	77.5	30.4	29.0
ge.....	81.4	104.4	92.9	47.7	47.3	47.5	14.4	14.7	14.6	79.3	80.3	31.2	29.7
WESTERN NEBRASKA TYPES													
.....	89.1	106.1	97.6	44.8	43.6	44.2	12.6	12.6	12.6	78.0	76.5	32.4	31.6
.....	71.9	98.9	85.4	49.2	47.2	48.2	15.6	14.8	15.2	83.8	79.8	34.4	31.1
ge.....	80.5	102.5	91.5	47.0	45.4	46.2	14.1	13.7	13.9	80.9	78.1	33.4	31.3

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*mary of Histological Leaf Measurements of Corn Types When Moved from ns Native Nebraska Localities and Grown Both in Extreme Eastern and braska. 1916.**

Thickness of			Per cent of total leaf thickness of			Thickness of cuticle of			Per cent of epidermal thickness of			Number vascular bundles per cm. leaf width
Leaf	Upper epidermis	Lower epidermis	Upper epidermis	Lower epidermis	Total epidermis	Upper epidermis	Lower epidermis	Total cuticle	Upper cuticle	Lower cuticle	Total cuticle	
(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
					ACTUAL VALUES							
					Corn Grown in Lancaster County (Eastern Nebraska)							
Microns	*Microns*	*Microns*	*Per cent*	*Per cent*	*Per cent*	*Microns*	*Microns*	*Microns*	*Per cent*	*Per cent*	*Per cent*	
219.2	34.6	27.9	15.7	12.7	28.4	6.4	5.8	12.2	18.5	20.6	19.6	68.2
225.9	34.5	28.3	15.2	12.4	27.6	6.4	5.9	12.3	18.6	21.4	20.1	65.1
228.2	35.5	29.0	15.5	12.6	28.1	6.4	5.6	12.0	17.9	19.2	18.5	68.3
224.4	34.9	28.4	15.5	12.6	28.0	6.4	5.8	12.2	18.3	20.4	19.4	67.2
					Corn Grown in Kimball County (Western Nebraska)							
204.3	31.8	26.7	15.5	13.1	28.6	6.1	5.8	12.0	19.2	21.8	20.5	76.4
182.3	30.6	25.9	16.8	14.2	31.0	6.0	5.7	11.8	19.7	22.0	20.8	78.6
194.6	30.2	25.7	15.5	13.2	28.7	6.1	5.7	11.8	20.2	22.0	21.0	76.9
193.7	30.9	26.1	15.9	13.5	29.4	6.1	5.7	11.9	19.7	21.9	20.8	77.3
					RELATIVE VALUES							
					Corn Grown in Lancaster County (Eastern Nebraska)							
Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
100	100	100	100	100	100	100	100	100	100	100	100	100
103	100	101	97	98	97	100	102	101	100	104	102	95
104	103	104	99	99	99	100	97	98	97	93	94	100
					Corn Grown in Kimball County (Western Nebraska)							
100	100	100	100	100	100	100	100	100	100	100	100	100
89	96	97	108	108	108	98	98	98	103	101	101	103
95	95	96	100	101	100	100	98	98	105	101	102	101

iled from Tables 26 and 27.

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3 (continued).—*Summary of Histological Leaf Measurements of Corn Types When ed from Their Various Native Nebraska Localities and Grown Both in Extreme rn and Western Nebraska. 1916.**

f seed	Number of stomata per sq. m. m.			Length of stoma			Length of stomatal aperture			Length of epidermal cell		Width of epidermal cell	
	Upper epidermis	Lower epidermis	Average	Upper epidermis	Lower epidermis	Average	Upper epidermis	Lower epidermis	Average	Upper epidermis	Lower epidermis	Upper epidermis	Lower epidermis
	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)
ACTUAL VALUES													
Corn Grown in Lancaster County (Eastern Nebraska)													
	Microns	*Microns*	*Microns*	*Microns*	*Microns*	*Microns*	*Microns*	*Microns*	*Microns*	*Microns*	*Microns*	*Microns*	*Microns*
ebraska.	78.7	94.6	86.6	50.2	49.1	49.6	17.2	17.1	17.1	84.5	84.5	33.8	34.1
ebraska.	79.4	95.8	87.6	50.2	49.2	49.7	16.0	16.0	16.0	78.9	78.6	33.8	34.0
ebraska.	75.9	93.0	84.4	50.1	49.3	49.7	15.1	15.6	15.3	78.4	80.7	35.3	35.3
.....	78.0	94.5	85.9	50.2	49.2	49.7	16.1	16.2	16.1	80.6	81.3	34.3	34.5
Corn Grown in Kimball County (Western Nebraska)													
ebraska.	80.0	99.0	89.5	47.5	46.9	47.2	14.3	14.6	14.4	80.2	78.9	32.0	32.5
ebraska.	81.4	104.4	92.9	47.7	47.3	47.5	14.4	14.7	14.6	79.3	80.3	31.2	29.7
ebraska.	80.5	102.5	91.5	47.0	45.4	46.2	14.1	13.7	13.9	80.9	78.1	33.4	31.3
.....	80.6	102.0	91.3	47.4	46.5	47.3	14.3	14.3	14.3	80.1	79.1	32.2	31.2
RELATIVE VALUES													
Corn Grown in Lancaster County (Eastern Nebraska)													
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
ebraska.	100	100	100	100	100	100	100	100	100	100	100	100	100
ebraska.	101	101	101	100	100	100	93	94	94	93	93	100	100
ebraska.	96	98	97	100	100	100	88	91	90	93	95	104	103
Corn Grown in Kimball County (Western Nebraska)													
ebraska.	100	100	100	100	100	100	100	100	100	100	100	100	100
ebraska.	102	105	104	100	101	101	101	101	101	99	102	97	91
ebraska.	101	103	102	99	97	98	99	94	96	101	99	104	96

ta compiled from Tables 26 and 27.

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per unit of cross section, 100 and 115; (5) number of stomata per unit area of epidermis, 100 and 106; (6) length of stomata, 100 and 95; (7) length of stomatal aperture, 100 and 88; (8) length of epidermal cell, 100 and 98; and (9) width of epidermal cell, 100 and 93.

The immediate result of growing corn under more adverse climatic conditions, namely, shortage of heat units and moisture, is to reduce the vegetative development in all its phases. Stalks become shorter, and bear the ear closer to the ground; leaf development and the production of plant substances are markedly reduced. The general effect is to reduce the opportunity for transpiration and photosynthesis. Associated with this reduction in vegetative growth is found a reduction in the size of the vegetative unit—the cell. Accordingly, under the more adverse conditions the leaves are thinner, as are also the epidermis and the cuticle. The stomata are more numerous in a given area of leaf surface. The stomata as well as the stomatal apertures are somewhat reduced in size. Furthermore, the cells being smaller, more vascular bundles occur in a unit of cross-section.

The fallacy of viewing such changes as being teleological or purposive is seen in the existence of both favorable and unfavorable reactions to adverse climatic conditions, moisture shortage being one of these conditions. A reduction in the plant size and leaf area and stomatal aperture indicates favorable reactions for reduced water requirements. On the other hand, a thinner epidermis and cuticle and a relative increase in number of stomata and water carrying vascular bundles suggest greater water dissipating capacity, and, therefore, must be considered as an adverse development inconsistent with the idea of purposiveness. Probably the true explanation of these reactions is that the reduced turgor and reduced rapidity of cell division caused by limited moisture and heat results in a materially smaller physical development.

When a comparison is made of native adapted corn types grown in their respective home localities, a combination of two entirely distinct factors is involved in the relative plant development, namely heredity and environment. Differences due to

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stomata are somewhat shorter while the leaf and epidermal thickness are practically identical. Stomata are more numerous and in general the cell size is somewhat smaller.

Probably the actual hereditary differences existing between types adapted to favorable and to unfavorable climatic conditions may be best determined by growing them all comparatively in the same environment under favorable conditions. In general when grown in eastern Nebraska, (Lancaster County), western Nebraska corn was markedly smaller in size of plant, leaf area, and plant substance than was eastern Nebraska corn. On the other hand, the leaf thickness, epidermal and cuticular thickness, relative number of vascular bundles, number of stomata per unit leaf area, and size of stomata were rather similar for corn of both sources. The data suggested that a slightly smaller stomatal aperture associated with a somewhat smaller epidermal cell is characteristic of the short season dry land types of western Nebraska. This would not seem to be of any adaptive importance because the reduction is insufficient to act as a check upon transpiration, as may be seen in Table 30.

COMPARATIVE YIELDS OF NATIVE TYPES

During 1916 and 1917, the native corn types from various parts of the state were compared for yield at the Experiment Station. Yields were based on the center row of duplicate three-row fifteenth-acre plats in which only hills with a full number of plants, three per hill, and surrounded by a full stand, were harvested. The results are given in Table 29. The average yields for eastern, central and western Nebraska types for the two years were respectively: 59.8, 46.2, and 31.6 bushels per acre. The corresponding maturity dates were September 24, September 21, and September 12.

No attempt has been made in connection with these investigations to make a reliable comparative yield per acre test for the various native corn types. Such a test would involve the growing of each type at several different planting rates for a period of years in order to determine the optimum rate for each, and to average seasonal effects.† In any environment as a general rule the maximum yield is obtained for the smaller and earlier types at a thicker planting rate than for the larger, later maturing types. Tests of this sort have almost universally been made at a single arbitrary planting rate which is likely to be too thin for the smaller types when compared under favorable growing conditions, and too thick for the larger types when compared

†Kiesselbach, T. A., 1918, Nebraska Agricultural Experiment Station Research Bulletin No. 13, pp. 45-47.

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E 29.—*Yields of Corn Types When Moved from Their Various Native Nebraska Localities and Grown Three* Plants Per Hill at the Experiment Station (Lancaster County) 1916-1917.*

ırce of seed	Date tasseling			Date ripe			Yield grain per acre		
	1916	1917	Average	1916	1917	Average	1916	1917	Average
County							*Bushels*	*Bushels*	*Bushels*
EASTERN NEBRASKA TYPES									
lson	7-31	8-8	8-4	9-21	10-1	9-26	64.0	63.0	63.5
ter	7-27	8-5	8-1	9-20	10-1	9-25	66.9	65.0	65.9
gton	7-30	8-7	8-3	9-18	10-4	9-26	68.0	66.7	67.8
on	7-25	8-1	7-28	9-14	9-20	9-17	47.3	47.3	47.3
ls	7-29	8-5	8-1	9-22	9-28	9-25	55.0	55.2	55.1
age			8-1			9-24			59.8
CENTRAL NEBRASKA TYPES									
y	7-20	7-31	7-25	9-16	10-1	9-23	52.1	59.2	55.6
	7-24	7-31	7-27	9-15	9-28	9-21	47.6	44.5	46.0
	7-15	7-28	7-21	9-12	9-26	9-19	40.5	42.7	41.6
	7-16	7-30	7-23	9-12	9-26	9-19	45.7	37.5	41.6
age			7-24			9-21			46.2
WESTERN NEBRASKA TYPES									
l	7-13	7-25	7-19	9-8	9-12	9-10	27.3	26.7	27.0
	7-15	8-1	7-23	9-12	9-18	9-15	39.1	33.6	36.3
age			7-21			9-12			31.6

se yields probably do not do full justice to the central and western Nebraska types since experience has ed that the optimum rate of planning for the smaller types is greater than for the larger eastern types.

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TABLE 30.—*Transpiration Relationship of Native Corn from Relatively Dry and Humid Regions. Four Years Average, 1914-1917.*

Source of seed and variety	Native county	Height of plant	Total dry matter	Leaf area per plant	Total water transpired	Transpiration per gram dry matter	Transpiration per square inch leaf area
(1)	(2)	*Inches* (3)	*Grams* (4)	*Sq. in.* (5)	*Kilo.* (6)	*Grams* (7)	*Grams* (8)
			WESTERN NEBRASKA				
Marten's White Dent	Kimball	72	286	675	68.479	240	101
Calico	Lincoln	88	441	995	103.078	233	103
Average		80	363	835	85.778	236	102
			EASTERN NEBRASKA				
Hogue's Yellow Dent	Lancaster	109	513	1,270	123.947	240	98
*University No. 3	Wayne	94	426	1,049	105.359	250	105
Average		101	469	1,159	114.653	245	101
			NEW YORK STATE				
Rocky Mountain Dent		93	384	891	92.861	235	105
Wood's White Dent		96	442	1,107	101.576	232	94
Average		94	413	999	97.218	233	100

The data in columns 7 and 8 are averages of ratios for the four years and not ratios of averages.
*University No. 3 originated six years prior to these experiments from native Wayne County (northeast Nebraska) corn, and is smaller and about one week earlier maturing than typical Lancaster County corn.

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under adverse conditions. In eastern Nebraska, the average optimum planting rate for small varieties is likely to be about 65 per cent thicker than for large varieties.

COMPARATIVE TRANSPIRATION OF EASTERN AND WESTERN CORN TYPES

The preceding morphological and histological adaptation studies have indicated that the chief adaptive characteristic of dry-land short-season corn was a marked reduction in vegetative growth. There was no definite indication of favorable structural adaptive reaction, tho a somewhat shorter stomatal aperture prevailed. This was regarded more as a dwarfish correlation, than as a directly adaptive feature. If adaptively effective, the shorter aperture should be expected to reduce the relative amount of transpiration per unit leaf area. This is not the case, as shown in Table 30.

Two native varieties each from western Nebraska, eastern Nebraska, and New York state were grown to normal maturity during four years, at the Nebraska Experiment Station, in large potometers, and the relative use of water determined. The native climates of western Nebraska, eastern Nebraska, and New York increase progressively in precipitation, and atmospheric humidity. Accordingly, this investigation affords an opportunity to study the adaptation occurring in corn as a reaction to moisture shortage. The method for determining the transpiration is the same as that described in Nebraska Research Bulletin No. 6, 1916, pp. 45, 48 and 49.

The transpiration per square inch leaf area was practically the same for corn native to all three regions. For western Nebraska, eastern Nebraska, and New York types it was respectively: 102, 101, and 100 grams water transpired per square inch leaf area. These cannot be regarded as adaptive differences. On the other hand the total amounts of water transpired per plant were respectively: 85,778, 114,653, and 97,218 kilograms. Eastern Nebraska and New York corn transpired respectively: 34 and 13 per cent more per plant than western Nebraska corn. Comparing the two most extreme native Nebraska types tested, namely Kimball County and Lancaster County corn, we find that the latter used 81 per cent more water per plant, 3 per cent less per unit leaf area, and equal amounts per unit dry matter produced. The Lancaster County corn plants were 51 per cent taller, had 88 per cent greater leaf area and 79 per cent greater dry matter than the Kimball County corn.

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COMPARATIVE YIELDS OF CORN FROM VARIOUS SOURCES IN EASTERN NEBRASKA

The following test was made to throw light on two questions: (1) What variation in yield may be expected in corn grown by different farmers in the same community? and (2) How do local varieties compare in yield with varieties secured at some distance?

The tests were made at the Nebraska Experiment Station in Lancaster County. Yields were based upon the middle rows of well-replicated three-row plats of which the first fifty consecutive full-stand hills were harvested and air dried. Thus variation in stand, variety plat competition, and soil differences were rather largely eliminated. All being fairly large varieties, it would appear that a uniform rate of planting should give significant results.

Hogue's Yellow Dent corn has been grown at the Experiment Station for about twenty years and has long been regarded as unsurpassed in yield under Experiment Station conditions. The Nebraska White Prize corn grown at the Station has been regarded as one of the most productive white varieties and has been grown there for twelve years. The other local corn secured from ten near-by farmers has in most cases been grown by them ten or more years, and has been handled in the customary farm manner. Likewise the corn types secured from other eastern counties had been grown there for a long term of years and were regarded as fully adapted. The results are given in Table 31.

As an average for the three years, the home grown Hogue's Yellow Dent outyielded seed from all other sources. Of the local varieties the lowest yielder was 7.7 bushels less than Hogue's Yellow Dent. Three of the ten local corns yielded within 3 per cent as much as Hogue's, which yielded 6 per cent more than the average of all other local sorts.

Of the seed obtained at a distance from other eastern counties, one yielded 16.7 bushels less than Hogue's. Another yielded 10.5 bushels less. Three of the remaining five yielded within two bushels of the home-grown Hogue's Yellow Dent.

The data suggest that there may be considerable variation in yielding capacity of corn grown by different farmers in the same locality and also among corn secured from various distant sources. Seed from three southeastern counties with more favorable growing conditions averaged 56.9 bushels as against 66.7 bushels for home grown Hogue's Yellow Dent. Seed from four northeastern counties with somewhat shorter growing season but equal in rainfall, averaged 63.7 bushels. Thus the relative yields

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ıLE 31.—*Comparative Yield Test at the Nebraska Experiment Station of Corn Secured Locally, and from Distant Eastern Nebraska Localities. Three Year Average, 1915-1917.*

Native seed from		Variety or color	Total number of plats averaged	Rate per hill	Date tassel-ing	Date ripe	Shrink-age	Yield per acre
Grower	County						*Per cent*	
SEED FROM WITHIN FIVE MILES OF EXPERIMENT STATION								
ıska Experiment tion	Lancaster	Hogue's Yellow Dent	131	3	8–6	9–27	15.4	66.7
Roberts	Lancaster	Yellow	21	3	8–8	9–26	14.6	62.6
›ore	Lancaster	Moore's White Dent	21	3	8–7	9–26	13.2	65.3
anley	Lancaster	St. Charles White	21	3	8–5	9–26	14.8	63.1
Graham	Lancaster	Reid's Yellow Dent	21	3	8–7	9–26	17.0	61.8
Graham	Lancaster	Boone County White	21	3	8–9	9–26	18.0	59.4
Schoenleber	Lancaster	White	21	3	8–6	9–27	16.5	60.9
onson	Lancaster	Chase's White Dent	21	3	8–6	9–26	14.2	63.6
Jensen	Lancaster	Chase's White Dent	21	3	8–7	9–27	16.2	64.6
. Clarke	Lancaster	St. Charles White	21	3	8–5	9–26	12.1	65.9
y Darby	Lancaster	Yellow	21	3	8–7	9–27	15.3	59.0
ıska Experiment tion	Lancaster	Nebraska White Prize	21	3	8–7	9–27	14.3	63.4
SEED FROM OTHER EASTERN NEBRASKA COUNTIES								
Brush	Nemaha	Boone County White	17	3	8–11	10–3	22.0	50.0
Rist	Richardson	Reid's Yellow Dent	17	3	8–9	9–28	19.5	64.6
ım Ernst	Johnson	Nebraska White Prize	17	3	8–7	9–28	20.1	56.2
mith	Washington	Nebraska White Prize	17	3	8–8	9–27	14.7	60.4
rson Brothers	Wayne	Reid's Yellow Dent	17	3	8–5	9–24	8.4	63.5
Roggenbach	Cuming	Reid's Yellow Dent	17	3	8–6	9–27	12.4	65.8
Seymour	Dodge	Reid's Yellow Dent	17	3	8–8	9–27	13.2	65.0

All yields based on fifty normal hills in the center row of 3-row plats.

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32.—*Comparative Yields of Local Corn Versus Corn Imported from Other States. Two Year Average, 1916 and 1917.*

ce of seed	Variety	Total number of plats averaged	Rate per hill	Date tasseling	Date ripe	Shrinkage	Yield per acre
						Per cent	*Bushels*
	LOCAL NEBRASKA EXPERIMENT STATION VARIETIES						
Nebr.	Hogue's Yellow Dent	4	3	8–4	9–25	10.3	64.0
Nebr.	Nebraska White Prize	4	3	8–7	9–27	11.3	66.1
e.		4	3				65.0
	IMPORTED VARIETIES						
Ohio	Clarage	4	3	8–1	9–23	7.4	42.6
, Mo	Reid's Yellow Dent	4	3	8–6	9–28	13.6	60.2
Ill.	Reid's Yellow Dent	4	3	8–5	9–27	9.7	61.7
wa	Reid's Yellow Dent	4	3	8–7	9–27	7.8	65.6
, Ind	Reid's Yellow Dent	4	3	8–8	9–28	8.4	65.3
an, Kas.	Commercial White	4	3	8–9	10–2	21.9	55.4
an, Kas.	Pride of Saline	4	3	8–6	9–30	19.4	60.2
Minn.	Minnesota No. 13	4	3	7–30	9–17	6.0	40.3
s, S. D.	Disco Ninety Day	4	3	7–29	9–13	6.5	44.2
e.		4	3				55.0

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of: (1) Well-acclimated home-grown Station seed, (2) seed from three northeastern counties, and (3) seed from three southeastern counties were respectively: 100, 96, and 85.

The performance of the three Nebraska White Prize corn samples secured from different sources and compared at the Nebraska Station is of special interest. Seed which had been grown upward of thirteen years by the Experiment Station in Lancaster County and by William Ernst of Johnson County originated from seed grown by Lee Smith in Washington County. The grain yields of corn from the three sources were respectively: 63.4, 56.2, and 60.4 bushels per acre. Thoro local acclimatization improved it for Experiment Station conditions, whereas, seed having been acclimated farther southeast was thereby reduced in productivity for the conditions prevailing at the Experiment Station.

LOCAL CORN COMPARED WITH CORN FROM OTHER STATES

During 1916 and 1917 seed corn was obtained from eight neighboring states and compared at the Experiment Station with the two acclimated local varieties—Hogue's Yellow Dent and Nebraska White Prize. The imported varieties were obtained from the Experiment Stations of the respective states and were acclimated to the conditions prevailing at those Experiment Stations. One variety was grown from each state except Kansas, from which two varieties were tested. Methods of testing were the same as in the preceding tests. The results are given in Table 32.

In this test the two local varieties, Hogue's Yellow Dent and Nebraska White Prize, yielded respectively 64.0 and 66.1 bushels per acre with an average of 65 bushels. Of the nine imported corns, two yielded practically the same as the local, three yielded within four bushels, one nine and a half bushels less, and three more than twenty bushels less. The nine imported corns averaged ten bushels less than the local.

One may conclude from the data that, as a general principle, locally adapted seed is superior to seed haphazardly imported. However, the mere matter of distance is not an absolute deciding factor in adaptation. It is quite possible to secure highly productive seed from a distance, but such introductions may meet with disaster unless preceded by local experience with

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CORN INVESTIGATIONS

By T. A. KIESSELBACH

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SUMMARY

1. One of the outstanding considerations developed by these experiments concerning seed corn is the importance of adaptation. It is possible to move corn which is well adapted in one section of this State to another within the State where it will prove an almost complete failure. The degree of adaptation is dependent upon the degree of equilibrium between the plant requirements and its environmental growth conditions. The chief conflicting factors in this adjustment are: (1) Too late plant maturity for the length and character of the growing season; (2) too large inherent vegetative development with its proportional demand upon soil moisture, under conditions of moisture shortage; (3) too early maturity for the length of growing season available, which limits unnecessarily the length of time during which the plant may elaborate and accumulate organic materials; and (4) too small inherent vegetative development with its unnecessary physical limitation upon synthetic and accumulative processes.

Surveys of corn production in this State suggest that, in the main, corn types are being grown which meet the local environmental conditions fairly well. Marked cases of inadaptation are the exception. It may be readily observed that there is a gradual transition in the vegetative and associated ear characteristics of corn which is parallel with the transition in the climatic values from one region to another. Such transition is found both within standard varieties and between different varieties. There is an apparent tendency among growers to select corn types which are slightly too late maturing to produce the best results under their environment.

The corn crop has been found rather plastic, due to its heterozygous or complex hybrid composition, and may be made earlier or later, larger or smaller, thru selection. Such changes

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Many of the plant characters which are involved in adaptation are not inherited singly, but commonly go in groups of associated characters. As a consequence the selection for some single specific character is frequently attended by the indirect selection of a group of characters. Some of the adaptive characters which tend strongly to be associated or transmitted in groups are early maturity, small stature, ears low on the stalk, small leaf area, slender ears, and smooth, shallow kernels with horny endosperm. Selection toward the opposite extreme of any of these characters tends to result in a rather corresponding transition in all of the other associated characters. Exceptions occasionally occur to these groupings of plant characters.

2. Continuous selection within a commercial variety at this Station during four years for opposite extremes in the ratio of leaf area to dry plant substance resulted in seven "high leaf area" and nine "low leaf area" strains of corn, in which the former, in comparison with the latter, averaged 23 per cent more leaf area per unit dry matter, 29 per cent greater actual leaf area, and five days later maturity. The high leaf area selections had ears of larger circumference, and deep, rough, starchy grain, whereas the low leaf area strains had more slender ears, with smooth, shallow, horny kernels. In a succeeding seven-year yield test, the low leaf area yielded 7 per cent more shelled corn per acre than the high leaf area type, but produced 4 per cent less than the original corn from which it was selected. An F_1 cross between these two leaf area types yielded 2 per cent more than the original corn during the seven years. The data suggest superiority of the low leaf over the high leaf area strains but also that some reduction in yield has resulted from narrow breeding brought about by too restricted type selection.

3. Annual selections of various ear types of a standard local variety, Nebraska White Prize, during a six-year period, indicate that long, slender, smooth seed ears with a relatively short and flinty kernel excelled large, rough, deep, and starchy grained seed ears by 9 per cent and the original unselected corn by 1.4 per cent. In another six-year test with standard Reid's Yellow Dent in which continuous selection was practiced, the long, smooth type of ears surpassed the standard medium, rough type 7 per cent. In a two-year test with local Hogue's Yellow Dent corn, long, slender ears with a rather smooth, shallow kernel excelled ears with deep, rough kernels 9 per cent and the original corn 8 per cent in yield of grain. While complete notes descriptive of the plant development resulting from these ear

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type selections were not taken thruout the entire period of the tests, the measurements and observations made lead to the conclusion that ear type selections indirectly result in a selection of correlated plant characteristics which differ in their adaptation to various environmental conditions. Selection of long, slender, smooth ears results in the isolation of types having a smaller and earlier maturing vegetative development than where the opposite large, rough type of ear is selected.

4. In an extensive comparative one-year test of ears disease free versus ears infected with root-rot diseases, as determined by the germinator test, the original unselected corn yielded 49.7 bushels, the disease free 50.2 bushels, and that designated as badly diseased corn 50.6 bushels per acre. No advantage resulted in regard to grain yield, barrenness, lodging, or soundness from such disease free selection. On the other hand, when the ear-to-row plats involved in this test are classified into rough, medium, and smooth groups without any reference to the presence or absence of root-rot diseases, the respective relative yields of shelled grain per acre are 100, 103, 106 as compared with 102 for the original unselected corn. Previous correlation of the germinator results with the various ear and kernel types indicates from 10 to 20 per cent greater freedom from root-rot diseases in case of the slender, smooth ear with horny kernels than in case of the large, rough, starchy, deep-grained ear. It seems possible that the increased yield secured by some investigators following selection of disease-free ears by the germinator test is, in part at least, associated with their prescribed preliminary selection of the smooth, slender, horny ears for seed purposes. Wherever corn types are being grown which tend to be somewhat too large and late maturing for their environmental conditions, selection of this smooth type of ear, whether because of root-rot disease considerations or otherwise, is likely to result in increased production because of the better adaptation of plant types represented in this type of ear. These type considerations apply where the various types are selected from the same general variety of corn.

In the case of seed grown under field conditions of promiscuous pollination, the progeny shows a tendency to come true to the ear type planted. In 1921, the percentages of rough, medium, and smooth ears harvested from large rough ears, long smooth ears, and the original unselected Nebraska White Prize corn were respectively 52, 35, and 13 per cent, 16, 40, and 44 per cent, and 30, 38, and 32 per cent. The difference in ear circumference, number of rows on an ear, and kernel length between these

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rough and smooth ear types averaged during six years approximately one-third as great for the ears harvested as for the ears planted. The progeny of the rough ears used in our disease study contained approximately 14 per cent more rough ears than did the progeny of the smooth ears; while on the other hand, the progeny of the smooth ears contained approximately 13 per cent more smooth ears than did the progeny of the rough ears. The progeny of the medium smooth ears was intermediate in both cases.

5. Continuous selection and testing of ears high versus ears low on the stalk during five years resulted in a spread of 23 per cent in ear height and a corresponding spread of 10 per cent in stalk height, based on the low ear selections. The low ear selections yielded 3.9 per cent more grain than the high ear selections, but 3.0 per cent less than the original corn. During the same period continuous selection and testing of seed ears from standing versus lodged plants resulted in a yield 10.9 per cent greater for the standing than for the lodged plants, and 2.9 per cent greater yield than was secured from the original corn. Continuously selected, during five years, ears borne erect on the stalk, as compared with drooping ear selections, yielded respectively 5.1 and 0.7 per cent less than the original corn.

6. In a six-year test, seed from the butts, tips, and middles yielded respectively 59.4, 60.4, and 60.2 bushels per acre. Little is to be gained from discarding butts or tips, aside from securing a more even stand, and a better germination under certain conditions of freezing injury. In a two-year test, corn selected when fully mature and at five weekly intervals before maturity yielded respectively 64.5, 64.0, 65.0, 63.0, 64.0, and 63.4 bushels per acre. The earlier selections required great care in curing. The data suggest that the selection of slightly immature seed corn to avoid freezing injury or for any other reason would not be objectionable if it is properly cured.

7. Seed selections of high viability made during three years from the field in September, November, and March gave respective yields of 47.0, 48.3, and 49.8 bushels per acre, as compared with 49.2 bushels for corn selected in the ordinary manner at husking time. Altho the time of selecting seed corn is

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These methods differ primarily in the manner of continuing the high yielding ear-to-row strains as established in the initial ear-to-row tests. They are: (1) Continuous ear-to-row breeding; (2) increasing a single high yielding strain in isolation; (3) increasing a composite of several high yielding strains in isolation; and (4) crossing several high yielding strains.

During a seven-year yield test, seed derived by these four practices yielded respectively 0.6 per cent less, 10.9 per cent less, 2.6 per cent more, and 1.7 per cent more than the original corn. The great reduction in yield resulting from a single high yielding ear-to-row strain continuously grown in isolation is doubtless due to close breeding.

In a five-year test of ear-to-row strains with a different local variety, (1) continuous ear-to-row breeding resulted in 0.8 per cent lower yield than the original, (2) increasing the eight best strains in composite under isolation yielded 4.7 per cent less than the original, and (3) crossing of ear-to-row strains yielded 1.7 per cent more than the original corn.

Improvement in yield of an adapted variety thru ear-to-row breeding seems rather uncertain, and 2.6 per cent increase is the maximum attained in these experiments. In the initial ear-to-row tests, the strains which were continued in these experiments had yielded approximately 20 per cent more than the original corn.

9. As an average for eleven years, corn selected from an isolation seed plat in which the poorest half of the stalks were annually detasseled gave a grain yield 1.8 per cent greater than seed from a corresponding plat in which the best half of the stalks were kept detasseled. However, both yielded slightly less than the original, thus indicating that no actual improvement resulted from continuous detasseling of the stalks that appeared to be inferior.

10. Three plants per hill in hills 42 inches apart is regarded as the standard planting rate for corn in eastern Nebraska and in a large part of the corn growing area elsewhere. Seed selected continuously from corn grown at this rate has

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1, 3, and 5 plants per hill yielded relatively 99.8, 100.0, and 100.4 per cent. It does not appear advantageous to select seed from corn planted thicker than the standard planting rate; and as an average for the two varieties, a reduction in yield not greater than 2 per cent is suggested in case the seed is all continuously selected from such a very thin stand as one plant per hill.

11. Self-fertilization as it occurs ordinarily in the field seems not to exceed 1 per cent under our conditions. Our tests indicate that only 0.7 per cent of the kernels were actually selfed under natural field conditions.

12. In an eight-year yield test, seed selected from detasseled rows in a seed plat yielded 0.6 per cent more than did seed taken from normally field pollinated rows. This would indicate that no extensive self-fertilization had taken place, since selfing reduces the yield approximately one-third in the first generation. The immediate effect of detasseling upon the current crop was an increased grain yield of one per cent for the detasseled plants.

13. Extensive observations have shown that in general the pollinating period of the tassel materially overlaps the silking period. Self-pollination might occur extensively were it not for the overwhelming preponderance of foreign pollen scattered promiscuously thru the air.

14. The continuous natural segregation and recombination of elemental hybridizing characters together with the natural element of survival of the fittest accentuated by man's repeated selection of well-developed ears for seed may account in a large measure for the inherently high productivity of field corn as now grown.

15. More than one hundred distinct pure lines or elemental strains have been developed in these experiments by continuous self-fertilization for seven or more years. Such self-fertilization

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yield of grain was 35 per cent of the original corn. Individual yield tests of 32 inbred strains of Hogue's Yellow Dent corn for briefer periods indicate considerable variation in grain yield. In one experiment, the use of the lowest yielding pure lines as one of the parents resulted in hybrid yields of 13.5 bushels less per acre than where both inbred parents were relatively higher yielding. In another two-year test with eighteen F_1 hybrids, groups of the five highest, eight intermediate, and five lowest yielding hybrids produced relative grain yields of 100, 89, and 65; while the average grain production per plant of the inbred parent strains of these three groups was respectiyely 100, 86, and 65 per cent. This suggests that crossing the more productive pure lines is likely to result in the most productive hybrids.

16. In a four-year test of eight F_1 hybrids between pure lines, the average yield surpassed the original corn 17.2 per cent while the most productive hybrid excelled the original by 30 per cent. A perplexing question arises from the fact that during one year of this test the same eight hybrids averaged 9 per cent less than the original. Altho the grain yields of these hybrids averaged 9.7 per cent more than the original corn during 1915 and 1916, their plant development was smaller. They were four inches shorter and had 18 per cent less leaf area. This does not suggest a correlation between grain production and vegetative vigor as measured in plant size. It doubtless indicates both the complete elimination of some deleterious factors which were present in the original variety and also the isolation and recombination of superior factors thru the inbreeding and hybridizing processes.

17. During two years, 29 F_1 hybrids between pure lines were compared with the original corn from which they were developed. The inbred parents of these hybrids were derived from plant types which had been partially fixed by continuous plant type selection for either a high proportion or a low proportion of leaf area per unit of mature dry plant weight. The relative grain yields of the (1) original corn, (2) low leaf area hybrids, (3) high leaf area by low leaf area hybrids, and (4) high leaf area hybrids were 100.0, 112.0, 107.4, and 100.9. The highest yielding individual hybrid surpassed the original corn 34 per cent. The correlated low leaf area ratio and slender, smooth, horny ear and low actual leaf area on the one hand, and the high leaf area ratio and large, rough, starchy ear and high actual leaf area on the other hand, were retained thruout the inbreeding process and transmitted to their hybrid offspring.

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Comparing the low leaf area and high leaf area groups (1) before inbreeding, (2) as inbred strains, and (3) as F_1 hybrids between these strains, the respective relative values for the following characters were: (1) Ratio of leaf area to dry matter, 82:100, 84:100, and 82:100; (2) actual leaf area per plant, 77:100, 76:100, and 82:100; (3) total dry matter, 95:100, 94:100, and 99:100; (4) ear weight per plant, 99:100, 125:100, and 107:100.

These data indicate that the outcome of inbreeding and hybridizing experiments may be quite extensively directed thru previous selection.

18. In a two-year test in which seven first and second generation hybrids were compared with the original corn, the respective relative yields were 125, 67, and 100. If the segregation of factors pertaining to grain yield should occur in the simple Mendelian ratio, the yield of the F_2 hybrids might be expected to center between the average of the pure line parents and their F_1 hybrids. During 1916 and 1917 the pure line parents approximated 24 per cent of the F_1 yield. A theoretical F_2 yield intermediate between these pure line and F_1 hybrid yields would have been 62 per cent of the hybrid yield, whereas the F_2 actually yielded 53 per cent as much.

These data show very definitely the inadvisability of selecting seed corn from an F_1 hybrid between such pure lines, no matter how productive the F_1 generation may be.

19. Very different results were obtained from hybrids between ordinary commercial varieties. In a four-year test, the yield of thirteen variety hybrids averaged 4 per cent less than the average of both parents, and 9 per cent less than the best parent. No hybrid equaled the best variety parent in grain yield. This failure of the F_1 hybrid to be more productive than the average of the two parents may be accounted for by the fact that the varieties are already fully heterozygous. For the same reason the F_2 generation of the variety hybrids yielded fully up to the F_1 generation. All plants of the second generation were as heterozygous as were plants of the F_1 generation.

In these experiments, seed for the F_2 generations for both pure line and variety hybrids was produced by crossing F_1 plants, and not by self-fertilization. The latter procedure would doubtless have reduced the F_2 variety yield approximately the same as the F_2 pure line yield was reduced. The method employed in these experiments corresponds to a farmer's procedure in selecting seed ears from an F_1 hybrid field.

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20. A histological study of ten pure line hybrids and their pure line parents indicates that the increased growth of the hybrid has its basis in both increased size and increased numbers of cells. Thru hybridization (1) the stalk diameter was increased 46 per cent, (2) the number of vascular bundles 45 per cent, (3) the bundle diameter 15 per cent, (4) the number of pith cells along one stalk diameter 38 per cent, (5) the diameter of one pith cell 8 per cent, (6) the length of one pith cell 10 per cent, (7) the leaf thickness 14 per cent, (8) the leaf epidermal thickness 4 per cent, (9) the number of vascular bundles in one cm. leaf width was reduced 8 per cent, which suggests larger cellular development within the leaf, and (10) the average width of the leaf epidermal cell was increased 4 per cent, which suggests greater number as well as greater size of the cells, since the total leaf area per plant increased 45 per cent. As an average for seven of these hybrids, the stalk volume was increased 235 per cent, whereas the stalk pith cell was increased only 26 per cent in volume. Approximately 90 per cent of the increase in plant size due to crossing results from an increase in cell numbers and 10 per cent from an increase in cell size.

21. During seven years, comparative yields are available for several different degrees of inbreeding as applied to ear-to-row strains. These degrees differ in the likelihood of related gametes being involved in the fertilization process. Four successive degrees of complexity in the gametic relationship resulted in yields of 16.8, 42.2, 49.2, and 54 bushels per acre as compared with 53.1 bushels for the original corn.

In another five-year comparison with a different variety, seed of ear-to-row strains continuously subjected to different degrees of gametic relationship yielded successively 22.3, 42.7, 46.8, 51.3, and 64.8 bushels per acre as compared with 63.7 bushels for the original corn. It becomes apparent from these tests that any selection or breeding practice which so restricts the breadth of the parental relationship as to increase the likelihood of identical Mendelian factors being paired upon fertilization is likely to give reduced yields.

22. In previous statements concerning first generation corn hybrids, it was pointed out that in case of pure line hybrids great increase in production over the parents resulted, whereas this did not hold in case of hybrids between fully heterozygous commercial varieties. A similar situation was found in the immediate effect of crossing upon kernel weight. Both the embryo and endosperm of the corn kernel being subject to crossing, we

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have in the embryo and endosperm of the kernel an actual hybrid product, just as we have in the plant produced when the seed is planted. We should expect increased hybrid vigor or a lack of it to be imparted to the kernel to correspond with that of the hybrid plant which it produces. In these experiments the immediate effect of foreign pollen from one commercial variety upon another was negligible, whereas hybrid kernels on pure line ears were increased relatively an average of 11 per cent.

There is nothing in these data which suggests that the results from comparative tests of commercial varieties of dent corn, as now conducted, are seriously invalidated because of any complicating immediate effect of fertilization by foreign pollen.

23. As an average for seven years, Hogue's Yellow Dent corn yielded 36.6, 44.6, and 40.3 bushels per acre, respectively, when grown at the rates of one, three, and five plants per hill in hills 3.5 feet apart. At similar rates in an eight-year test, Nebraska White Prize corn yielded 37.1, 52.9, and 49.4 bushels respectively. In a four-year test, the planting rates of one, two, three, four, and five plants per hill yielded respectively 40.7, 49.4, 52.9, 50.7, and 49.3 bushels per acre. Evidently there may be considerable variation in stand, fluctuating about three plants per hill, under Experiment Station conditions, without a material effect upon yield.

24. In a five-year test to determine the effect of ununiform distribution of plants in the field, the following varied distributions were compared: (1) Uniformly three plants per hill, (2) alternating hills with two and four plants, (3) alternating hills with one, two, three, four, and five plants, and (4) alternating hills with one, three, and five plants. The respective yields of grain per acre for these methods of distribution were: 59.0, 59.2, 58.6, and 56.0 bushels.

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CORN INVESTIGATIONS

By T. A. Kiesselbach

INTRODUCTION

The purpose of the investigations reported in this bulletin has been primarily to determine some of the underlying principles involved in corn improvement. The work comprises a study of some of the physiological characteristics of the crop together with a comparison of various selection, breeding, and cultural practices in their relation to grain yield. The experiments were made largely on the Agricultural Experiment Station farm or within its immediate vicinity, at Lincoln, Nebraska, except in a few instances where the nature of the investigation required other designated locations.

The investigations reported herein are in part a continuation and extension of work done by Lyon and Montgomery prior to 1911 and reported by them in earlier publications. There has been perfect continuity in some of these experiments for the last eighteen years. This has been made possible by the complete records kept thruout their progress, and also by the fact that Montgomery and the writer were each in turn associated for a number of years with their predecessors in these corn experiments.

The acreage devoted to these studies during the last ten years has varied from thirty to sixty acres annually. The seasons of 1918 and 1919 were so dry at the Station that the corn grown in these experiments was virtually a failure both years and was used for silage without yield determinations. Thus, many of the data in the following tables terminate with the 1917 crop.

Acknowledgment for efficient assistance at various times during the course of these experiments is made to Messrs. J. A. Ratcliff, C. A. Helm, F. D. Keim, H. G. Gould, Arthur Anderson, W. E. Lyness, H. A. Jones, and Enoch Nelson.

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Many of the problems investigated in these experiments have been studied elsewhere by other workers,[1] with varied results and conclusions. One probable cause for this diversity of results from certain selection and breeding practices is the use, by different investigators, of varieties differing in their degree of local adaptation. It is reasonable that a poorly adapted variety is more likely to respond favorably to selection and breeding than is a well-adapted variety. The process of improvement in such a case may simply be that of directed acclimatization. This diversity of results is doubtless also to be accounted for, in part, by experimental errors which have unconsciously modified the correct indications. Method studies, such as reported in Nebraska Agricultural Experiment Station Research Bulletin No. 13, indicate many sources of possible error. These chiefly arise from irregularities in stand and soil, insufficient numbers of individuals and replications of plats, competition with adjacent unlike sorts, and insufficient duration of tests.

Some experiments are greatly subject to seasonal effects and require continuation thru a period of years in order to secure average indications. The nature of other experiments is such that the seasonal variation is not a vital factor, and dependable indications may be had in a much shorter time, provided the number of replications is ample and the method employed is correct.

ECONOMIC CONSIDERATIONS

The United States produces, in round numbers, 3,000,000,000 bushels of corn annually. Nebraska's normal corn crop approaches 200,000,000 bushels. (Table 1.) An increase in the acre yields accompanied by an improvement in or at least maintenance of commercial quality would be a matter of no small moment. The significance of improvement along these lines, even tho slight, is so profound that agricultural agencies seem justified in the expenditure of great effort to establish the essential considerations in such improvement. An annual increase of approximately seven million bushels in Nebraska's corn crop would result from increasing the average yield one bushel per acre.

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[1]The literature bearing upon many of the problems investigated herein is so extensive that it has seemed expedient to completely omit all literature citations.

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Furthermore, negative data which fail to show constructive improvement in productivity have often positive values in indicating practices which fail to promote desired results. Strictly technical investigations sometimes reveal quite unexpected practical possibilities.

TECHNIQUE OF THE FIELD PLAT YIELD DETERMINATIONS

Since 1911, except where the nature of the experiment required otherwise, the corn has been planted thick and thinned to the desired uniform rate. In the main, the corn rows have been

TABLE 1.—*Annual acreage and yield of corn, wheat, and oats in Nebraska, 1890 to 1921.*

Crop	Total acreage	Yield per acre
	Acres	*Bushels*
NINE-YEAR PERIOD, 1890 TO 1898		
Corn	5,419,000	20.5
Wheat	1,399,000	14.7
Oats	1,482,000	24.9
NINE-YEAR PERIOD, 1899 TO 1907		
Corn	6,256,000	28.6
Wheat	2,269,000	18.1
Oats	1,970,000	28.5
NINE-YEAR PERIOD, 1908 TO 1916		
Corn	6,530,000	25.7
Wheat	3,131,000	17.9
Oats	2,219,000	27.6
FIVE-YEAR PERIOD, 1917 TO 1921		
Corn	7,641,000	26.6
Wheat	3,321,000	14.0
Oats	2,537,000	30.9
FOUR-YEAR PERIOD, 1918 TO 1921		
Corn	7,240,000	26.4
Wheat	3,902,000	14.0
Oats	2,412,000	29.2
THIRTY-TWO YEAR PERIOD, 1890 TO 1921		
Corn	6,314,000	25.2
Wheat	2,431,000	16.4
Oats	1,991,000	27.6

Due to the severe winterkilling of the 1917 crop, much of the wheat acreage was replanted to other crops. The 4-year average, 1918 to 1921, therefore represents more nearly a normal average of the various crops than does the 1917-1921 average. These data are compiled from the annual reports of the Nebraska State Board of Agriculture.

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72 hills long, and the yields have been based on the first 50 hills in the row containing, and adjacent to hills having, a full stand of plants. All discarded and surplus hills are removed from the row, just previous to husking. Error in comparative yields due to accidental variation in stand is thus eliminated.

Wherever varieties or types under comparison were distinctly dissimilar in growth habits, three-row plats, rather than single rows, have been used to reduce error due to unequal plant competition in adjoining plats, and the middle row only was used for tests.

After marking the land off crosswise into rows 3.5 feet apart by means of a four-row sled marker, the corn was dropped into the hills by means of modified hand corn planters from which the internal mechanism had been removed. The kernels were space planted in the hill about four inches apart in order that the number of individual plants in the hill might be determined with ease before harvest without confusing suckers and main stalks. The customary rate has been three plants per hill.

The grain yields reported in the following experiments are for air-dry shelled corn per acre. Shrinkage and shelling percentages have been determined for each sort, from representative samples of ear corn saved in the fall at time of husking. These samples, commonly weighing about 30 to 40 pounds, were stored in a slightly heated seed house from November till March, when the percentages of water loss and of shelled corn were determined.[1]

In several instances, grain yields for 1911 do not correspond exactly with earlier published results for that year. This is due to the fact that the earlier published figures have been revised for air-dry shelled corn per acre.

Yield tests of corn resulting from breeding or selection experiments have always included the original variety, to serve as a measure of progress made in the selected stock. Since the

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have been grown annually in isolated fields at the Experiment Station. The seed has been continued from five hundred or more ears annually, selected at random after husking, the only requirement being that the ears so selected are well developed and sound. The original Hogue's Yellow Dent variety has been continued in the same manner at the Experiment Station since 1910. During the period of 1903 to 1910, seed of the original Hogue's Yellow Dent corn, to be used as a check, was obtained each year (at a distance of 30 miles) from the original grower.

These two varieties, Hogue's Yellow Dent and Nebraska White Prize corn, are both standard full season varieties, locally grown seed of which is well acclimated to conditions prevailing at this Station. Neither variety had ever been subjected to close type selection.

ADAPTATION

Under our conditions the importance of growing adapted corn can not be too strongly emphasized. It is the outstanding quality to be sought in seed corn. It surmounts all question of variety, ear and kernel type, color, and breeding. The characteristic differences between corn types adapted to various regional areas of Nebraska have been presented in Nebraska Research Bulletin No. 19. The following data in Table 2 and figures 1, 2, and 3, extracted from the above bulletin, illustrate the significance of growing well-adapted corn.

In figures 1 and 2 are shown the mean climatic factors for this State, being compiled from thirty or more years' data by the Nebraska Weather Bureau under the direction of G. A. Loveland. Progressing westward in the State, the rainfall decreases, the growing season shortens, and the temperature lowers. The westward lowering of temperature is due primarily to a rather gradual increase in altitude from 1,000 feet in the extreme east (Richardson County) to 5,000 feet in the extreme west (Kimball County). While there are also distinct soil differences within the State, they are far less potent factors in the local adaptation of corn than is climate.

Native full-season seed corn typical of the region was obtained from each of the eleven counties indicated by number in figure 1. These seed sources represent widely differing climatic areas, ranging from a relatively favorable corn climate in the east to a relatively less favorable corn climate in the west.

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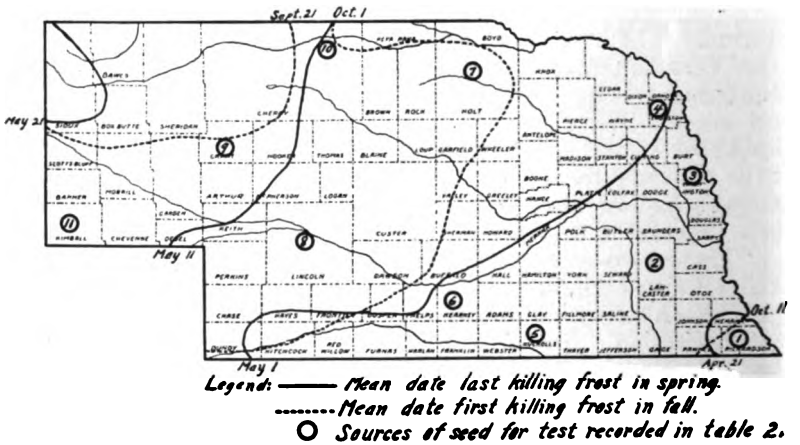
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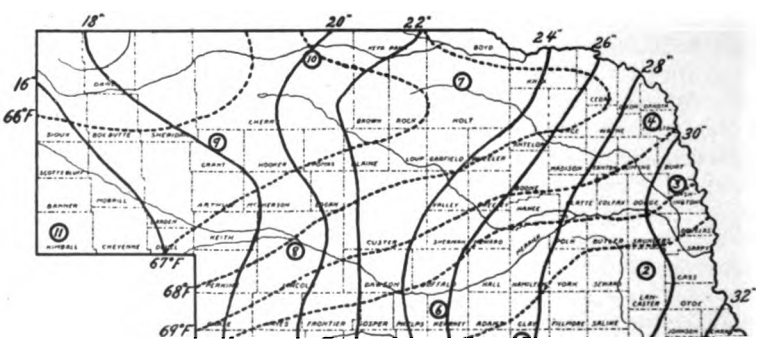
May 11
May 1
Oct. 11
Apr. 21
Legend: —— Mean date last killing frost in spring.
..... Mean date first killing frost in fall.
O Sources of seed for test recorded in table 2.

FIG. 1.—Average dates of the last killing frost in the spring and the first killing frost in autumn for various regions of Nebraska. The hereditary type of corn grown in different regions should vary in order to fit the length of frost free period available for growth.



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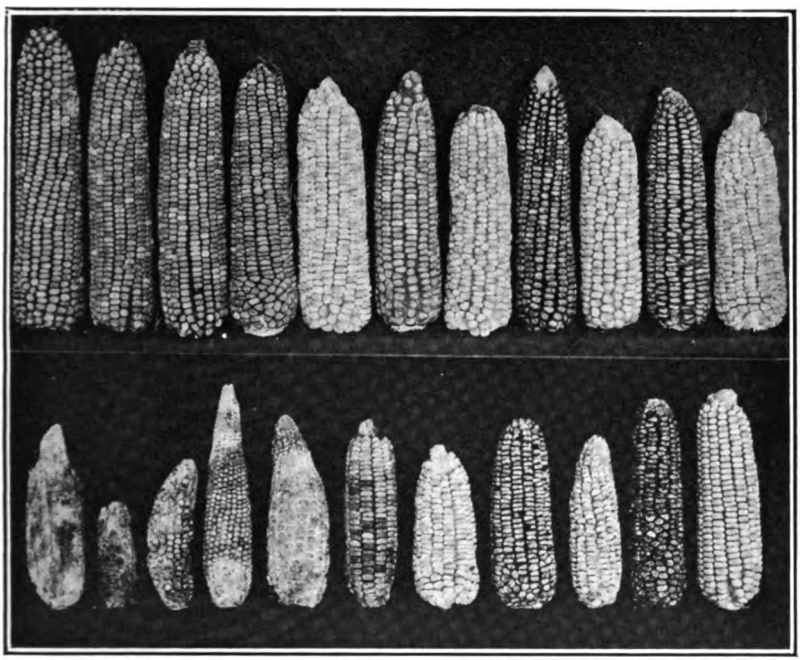

1 2 3 4 5 6 7 8 9 10 11

FIG. 3.—Representative ears of corn grown from native seed from eleven regional areas in Nebraska.

Top row: Corn grown in Lancaster County; Bottom row: Corn grown in Kimball County.

Sources of seed: 1, Richardson County; 2, Lancaster County; 3, Washington County; 4, Thurston County; 5, Nuckolls County; 6, Kearney County; 7, Holt County; 8, Lincoln County; 9, Grant County; 10, Cherry County; 11, Kimball County.

These eleven native corn types were grown comparatively in 1916 in Lancaster, eastern Cherry, and Kimball Counties. The rate of planting in these three cases was normal for each region and was uniform for all types. Corn is seldom planted more than two-thirds as thick in western as in eastern Nebraska.

When compared under the favorable conditions of Lancaster County, seed from all sources matured satisfactorily. Grown in Kimball County, maturity was rather proportional to the proximity to the seed's source. In Cherry County, with its

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TABLE 2.—*Comparative measurements of corn plants adapted to various regions of Nebraska, when grown in Lancaster, Cherry, and Kimball Counties. 1916.*

Source of seed	Height		Leaf area per		Dry matter		Shelling per cent
	Stalk	Ear	Plant	Pound dry matter	Grain	Total	
County (1)	*Feet* (2)	*Feet* (3)	*Sq. in.* (4)	*Sq. in.* (5)	*Pounds* (6)	*Pounds* (7)	*Per cent* (8)
WHEN PLANTED IN EASTERN NEBRASKA (LANCASTER COUNTY)							
Richardson	8.3	4.2	1,298	1,165	.548	1.114	87
Lancaster	7.5	4.2	1,414	1,369	.528	1.033	87
Washington	7.8	4.3	1,407	1,506	.388	.934	85
Thurston	7.4	3.3	1,209	1,480	.363	.817	84
Nuckolls	7.5	3.4	1,459	1,325	.504	1.101	81
Kearney	6.9	3.5	1,259	1,570	.328	.802	83
Holt	6.8	3.2	1,219	1,390	.337	.877	78
Cherry	6.0	2.8	833	1,178	.289	.707	79
Lincoln	6.1	3.1	849	1,059	.352	.802	81
Grant	5.7	2.0	775	1,096	.284	.707	82
Kimball	5.4	1.7	594	1,167	.211	.509	78
WHEN PLANTED IN NORTH CENTRAL NEBRASKA (EASTERN CHERRY COUNTY)							
Richardson	6.6	2.6	1,094	1,602	.249	.683	79
Lancaster	7.1	2.9	959	1,475	.207	.650	72
Washington	7.4	2.7	991	1,573	.196	.630	72
Thurston	6.8	2.2	891	1,314	.286	.678	80
Nuckolls	7.3	3.1	1,066	1,485	.240	.718	77
Kearney	6.3	2.0	820	1,488	.141	.551	68
Holt	6.4	2.1	954	1,435	.262	.665	80
Cherry	5.8	1.7	624	1,042	.267	.599	80
Lincoln	6.4	2.1	840	1,321	.247	.636	77
Grant	5.4	1.3	587	1,075	.247	.546	79
Kimball	4.7	1.0	376	954	.194	.394	81
WHEN PLANTED IN WESTERN NEBRASKA (KIMBALL COUNTY)							
Richardson	6.9	3.0	1,050	3,144	.039	.334	74
Lancaster	6.0	2.2	1,100	4,089	.004	.269	55
Washington	7.4	3.0	1,140	3,238	.015	.352	41
Thurston	5.5	3.1	563	2,093	.033	.269	70
Nuckolls	6.0	2.0	1,042	2,463	.062	.423	77
Kearney	5.9	1.9	718	1,894	.119	.379	77
Holt	5.7	1.9	759	2,193	.073	.346	68
Cherry	4.9	1.4	536	1,605	.137	.334	78
Lincoln	5.1	1.6	491	1,705	.088	.288	73
Grant	4.9	1.6	426	1,479	.081	.288	70
Kimball	4.2	1.1	425	1,221	.161	.348	80

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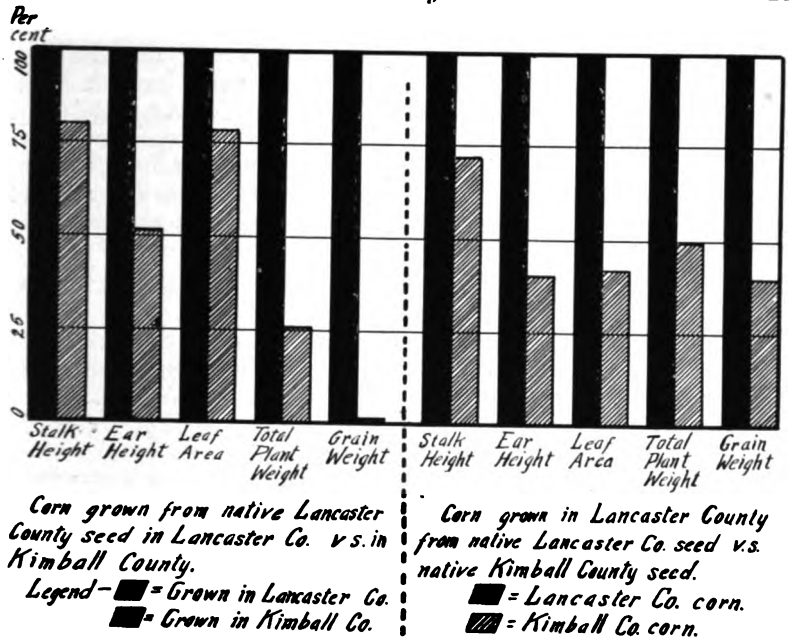

CHART 1.—Showing the significance of adaptation in corn production. At the left is shown the relative adaptation of a given lot of corn to two different environments. At the right is shown the comparative plant growth in a given favorable environment of two lots of corn adapted to two different environments. Compiled from Table 2.

rather intermediate climate, corn from the less favorable sources matured well, while from the sources of more favorable climate the corn was immature and chaffy.

Representative ears of corn from each source when grown in Lancaster and Kimball Counties are shown in figure 3. These data show some of the profound hereditary differences between native types from various climatic areas within the State.

VARIETY SIGNIFICANCE

Local adaptations within some of our standard varieties of corn are so marked that variety name has lost much of its significance in Nebraska. These distinct local variety types or subvarieties originate thru the natural processes of adaptation and thru the controlled selections by man. These controlled selections may be along the natural line of adaptation or to secure other economic advantages, or they are mere fanciful individualistic variations without immediate practical importance.

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Such local type differences within a variety may be illustrated by Table 3, which shows the comparative growth habits of typical Lancaster County and Thurston County Reid's Yellow Dent corn when grown comparably at the Experiment Station in Lancaster County. The northern seed obtained from one hundred miles farther north matured a week earlier and the plants were distinctly shorter and lighter weight, the ears were smaller and the kernels shorter and smoother, and the shelling percentage and shrinkage of ear corn were also somewhat less.

TABLE 3.—*Effect of adaptation upon variety characteristics. Thurston County acclimated and Lincoln County acclimated corn grown for the first year at the Experiment Station in Lancaster County in comparison with locally acclimated corn of the same varieties.*[1] *1916.*

Plant characters	Reid's Yellow Dent acclimated to		Calico acclimated to	
	Lancaster County	Thurston County	Lancaster County	Lincoln County
1 Date tasseling	7/31	7/25	7/31	7/15
2 Date ripe	9/21	9/14	9/20	9/8
3 Plant height (feet)	7.25	6.25	7.75	6.50
4 Ear height (feet)	3.75	3.25	3.50	3.00
5 Shrinkage of ear corn (per cent)	7.2	4.5	3.8	2.0
6 Shelling percentage (per cent)	85	82	83.6	79.6
7 Two-eared stalks, per 100 plants	7	7	0	3
8 Barren plants, per 100	2	2	9	3
9 Lodged plants, per 100	9	8	8	16
10 Yield of dry shelled corn per acre (bushels)	61.0	45.6	58.3	40.5
11 Leaf area, per stalk (sq. in.)	1,414	1,209	1,323	849
12 Stover weight, per stalk, moisture free (grams)	193	174	182	167
13 Ear weight, per stalk, moisture free (grams)	276	197	277	197
14 Total weight, per stalk, moisture free (grams)	469	371	459	364
15 Grain weight, per stalk, moisture free (grams)	234.6	165	231.6	160
16 Ear length (inches)	7.8	7.0	7.8	7.4
17 Ear circumference (inches)	6.4	6.1	6.5	5.8
18 Kernel length (inches)	.51	.47	.49	.45

[1] The first ten characters are the composite data for three field plats of 600 plants. The other measurements are based on ten representative successive plants for each plat. 1916 was a fairly normal year for corn.

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The table gives a similar comparison of Lancaster County and Lincoln County acclimated calico corn. When compared at the Experiment Station, Lincoln County seed, acclimated 210 miles west, produced plants which ripened twelve days earlier, were fifteen inches shorter, and had a somewhat lower shelling percentage and shrinkage of ear corn. The leaf area was only about two-thirds as great, the ears were smaller and smoother, and the kernel length shorter.

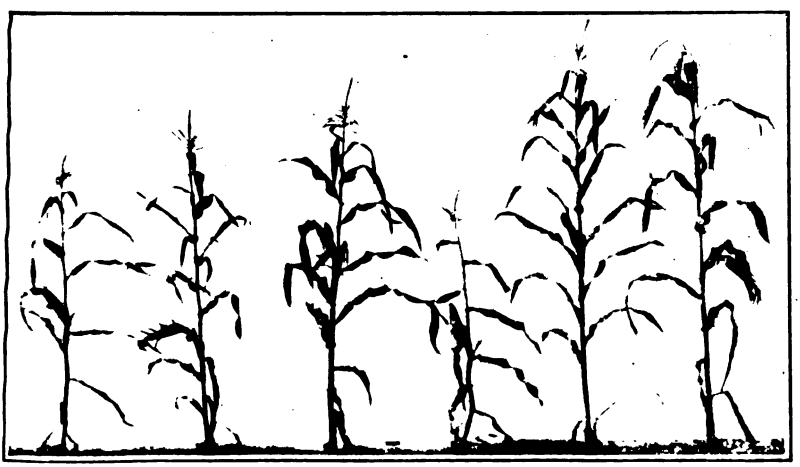

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FIG. 4.—Illustrating character of varieties acclimated to various regions. Typical plants grown at the Nebraska Experiment Station from seed obtained from the sources indicated. (1) Martens' White Dent from Kimball County, Nebraska; (2) Calico from Lincoln County, Nebraska; (3) Hogue's Yellow Dent from Lancaster County, Nebraska; (4) Minnesota No. 13 from North Dakota; (5) Commercial White from southeastern Kansas; (6) Reid's Yellow Dent from Indiana.

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TABLE 4.—*Comparative test of corn varieties. Four-year average, 1914-1917.*

Description	Date in tassel	Date ripe	Stalk height	Ear height	Suckers per 100 plants	Ears per 100 plants	Two-eared plants per 100	Shrinkage of ear corn	Shelling percentage	Yield per acre
			Inches	*Inches*				*Per cent*	*Per cent*	*Bu.*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Hogue's Yellow Dent	8/1	9/23	88	43	24	84	4	10.19	84	46.5
Reid's Yellow Dent	8/1	9/23	85	44	17	87	5	7.63	85.1	46.3
Calico	8/4	9/28	86	43	13	81	3	7.40	82.4	43.3
Leaming	7/29	9/23	87	43	13	80	3	8.46	82.8	43.1
University No. 3	7/29	9/21	78	40	11	81	1	8.85	82.7	43.0
Bloody Butcher	8/5	9/28	88	41	12	81	2	8.34	82.1	42.7
Nebraska White Prize	8/4	9/27	91	46	9	83	3	11.81	83.2	42.5
St. Charles White	7/30	9/22	82	39	2	82	1	7.92	84.3	40.1
Pride of the North	7/26	9/14	78	38	14	90	8	5.08	82.0	40.1
Iowa Silver Mine	8/1	9/25	83	40	10	80	2	9.44	82.2	39.3
Iowa Gold Mine	7/29	9/24	86	42	13	78	4	7.58	84.9	39.1
White Cap	7/28	9/21	78	41	5	86	3	4.96	83.9	37.1
Minnesota No. 13	7/22	9/10	68	35	4	86	2	3.98	81.9	35.7
Boone County White	8/7	9/29	91	41	5	78	3	19.26	80.7	35.6

The data are based on center rows of duplicate three-row plats, thinned to a uniform stand. The first fifty consecutive hills with normal stand were harvested from rows containing 72 hills.

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widely disseminated, and their name is more suggestive of the region to which they are adapted.

In the conduct of corn variety tests, it is difficult to eliminate from the seed the qualifying effect of local adaptations, especially when obtained from distant points. Yield differences in such tests are frequently the result of the combined effects of variety difference and local adaptation. Variety performance is subject to variation due to the source of the seed. Table 4 reports the yields during a four-year period of fourteen varieties, subject to local adaptation.

HOME GROWN VERSUS IMPORTED SEED CORN

During the three years 1915-1917, seed of acclimated corn being grown by ten local Lancaster County farmers living within five miles of the Experiment Station was compared for yield with seed corn obtained from seven more distant eastern Nebraska farmers, most of whom were making a specialty of seed corn production. The object was to determine the variation in the inherent productivity of corn grown by different farmers in a community such as this one, and the likelihood of advantageous substitution of some other local or imported corn. The results are given in Table No. 5.

Of the ten selections from local farmers, six yielded within 2½ bushels, or 4 per cent, as much as the average of the two standard Experiment Station varieties, viz, Hogue's Yellow Dent and Nebraska White Prize. The other four varieties yielded respectively 3.2, 4.1, 5.6, and 6 bushels, or 5.1, 6.5, 8.9, and 9.5 per cent, less than this average. Of the seven varieties from a distance, four yielded within one and one-half bushels, or 3 per cent, as much as the average for the two standard Experiment Station varieties. The other three yielded 4.6, 8.8, and 15 bushels, or 7.3, 14.0, and 23.8 per cent, less, respectively.

The results suggest that the majority of farmers in a community are probably growing corn of about equal productivity. A few have corn sufficiently inferior to invite substitution. No individual farmer's corn is likely to be very outstanding in its superiority.

The best imported seed did not surpass the best local seed, which is rather encouraging for the use of home grown seed corn. The least productive of the imported varieties was far inferior to the lowest yielding home grown kind, which suggests the need for great caution when procuring seed corn from a distance.

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Comparative test of corn varieties obtained from farmers in the vicinity of the Ex-nt Station and varieties obtained from somewhat distant eastern Nebraska counties. year average, 1915, 1916, and 1917.

of seed / d	County	Variety	Date in tassel	Date ripe	Stalk height	Ear height	Suckers per 100 plants	Ears per 100 plants	2-eared plants per 100	Shrinkage of ear corn	Shelling per cent	Yield per acre
	(2)	(3)	(4)	(5)	*In.* (6)	*In.* (7)	(8)	(9)	(10)	*Per cent* (11)	*Per cent* (12)	*Bu.* (13)
on..	Lancaster...	Hogue's Yellow Dent...	8/6	9/27	94	46	24	95	23	15.4	84.0	66.7
....	Lancaster...	Reid's Yellow Dent....	8/8	9/26	91	47	10	92	24	14.6	84.8	62.6
....	Lancaster...	Moore's White Dent...	8/7	9/26	91	45	13	94	25	13.2	83.4	65.3
....	Lancaster...	St. Charles White.....	8/5	9/26	90	45	6	95	22	14.8	84.9	63.1
....	Lancaster...	Reid's Yellow Dent....	8/7	9/26	94	48	13	90	23	17.0	84.6	61.8
....	Lancaster...	Boone County White...	8/9	9/26	93	45	12	85	21	18.0	82.4	59.4
r...	Lancaster...	White Dent.....	8/6	9/27	92	46	16	88	22	16.5	82.9	60.9
....	Lancaster...	Chase's White Dent....	8/6	9/26	86	44	15	86	20	14.2	83.2	63.6
....	Lancaster...	Chase's White Dent....	8/7	9/27	92	43	21	92	19	16.2	82.5	64.6
....	Lancaster...	St. Charles' White	8/5	9/26	87	43	9	98	25	12.1	82.9	65.9
....	Lancaster...	Darby's Yellow Dent...	8/7	9/27	98	47	8	90	19	15.3	82.9	59.0
on..	Lancaster...	Nebraska White Prize..	8/7	9/27	97	49	13	91	24	14.3	82.6	63.4
		Average.....	8/7	9/26	92	46	13	91	22	15.1	83.4	63.0
		VARIETIES FROM VARIOUS EASTERN NEBRASKA COUNTIES										
....	Nemaha....	Boone County White...	8/11	10/3	96	44	9	83	6	29.0	80.2	50.0
....	Richardson..	Reid's Yellow Dent....	8/9	9/28	95	47	13	96	21	18.3	84.1	64.6
....	Johnson....	Nebraska White Prize..	8/7	9/28	97	48	8	90	22	18.61	82.8	56.2
....	Washington.	Nebraska White Prize..	8/8	9/27	93	46	12	90	22	13.20	83.5	60.4
....	Wayne.....	Reid's Yellow Dent....	8/5	9/24	81	43	11	92	24	6.93	84.8	63.5
ih..	Cuming....	Reid's Yellow Dent....	8/6	9/27	93	46	11	93	20	10.89	85.3	65.8
....	Dodge.....	Reid's Yellow Dent....	8/8	9/27	97	49	7	95	23	11.83	83.4	65.0
		Average.....	8/8	9/28	93	46	10	91	20	15.5	83.4	60.8

cated six and seven times annually Yields based on center rows of three-row blocks.

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BROAD FERTILIZATION IN CORN THE RULE

RELATION OF SILKING AND POLLINATION

Knowledge that inbreeding of corn is injurious has caused considerable speculation relative to the amount of inbreeding that actually occurs in the open field pollination of corn.

For the purpose of determining the opportunity for cross-fertilization, the natural silking and tasseling relationships were studied during 1914 and 1915 for fourteen varieties. The varieties under comparison were grown at the normal rate of planting (three per hill) in adjacent three-row plats of sixteen rods length. One hundred and twenty consecutive plants were tagged and numbered in each plat just before the blooming period. With the initial advent of tassels and silks, individual plant records were kept of their daily development. The correlations between the shedding of pollen and the pollination of silks and, indirectly, the fertilization of the ovules, are presented in Tables 6 to 8 and summarized in Table 9. Data bearing upon the same relationships were obtained on a smaller scale with nine varieties in 1920 and are included in the summary table.

The upper portion of the central tassel spike is commonly the seat of the initial shedding of pollen. From here it extends downward and laterally to the tassel branches. The shedding of pollen begins with elongation of the anther filament and the extrusion and dehiscence of the anthers. Receptive silks are subject to self-fertilization as long as the plant bearing them sheds pollen. The exact time at which the pollen falls upon the silk which fertilizes the kernel is not directly apparent. This time can be approximated by noting the date upon which the characteristic slight discoloration and withering of the silk consequent upon fertilization is first apparent.

In 1921 the time of discoloration and withering of the silks, which is evidence of fertilization having been effected, ranged from 42 to 72 hours after the pollen had been applied to the silks. For this determination the ears of 100 plants were covered with paper bags before the silks appeared. Upon removal of the bags following silking, pollen was artificially applied and the time determined for each plant to show the effects. The data are given in Table 10.

Varieties as well as individual plants were found to vary somewhat in the sequence of the various flowering stages of tassel and silk. With all varieties, however, as an average for the two years and with most individual plants, it appears that

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TABLE 6.—*Relationship between the shedding of pollen, silking, and fertilization of corn. 1914.*

Variety	Number of plants averaged	Pollination period for variety (days)		Number of days shedding pollen (individual plant average)					Pollen maximum before silks indicate fertilization (days)	Maximum length of silks (inches)
		Maximum length	More than 12% plants shedding pollen	Entire period	Before silks appear	After silks appear	Before fertilization is apparent	After fertilization is apparent		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Reid's Yellow Dent	99	14	10	6.5	2.4	4.1	6.1	+0.4	2.8	2.2
Hogue's Yellow Dent	102	13	10	6.1	2.8	3.3	6.4	—0.3	3.6	2.1
Iowa Gold Mine	110	13	10	5.6	2.1	3.5	5.7	—0.1	2.8	2.0
Leaming	111	12	9	5.9	2.1	3.8	5.6	+0.3	2.5	2.2
Calico	109	12	9	5.7	2.5	3.2	6.0	—0.3	2.8	2.1
Bloody Butcher	110	13	10	5.7	2.2	3.5	6.3	—0.6	2.9	2.2
Boone County White	98	14	10	6.6	4.5	2.1	9.3	—2.7	5.8	2.1
St. Charles White	113	11	9	5.6	2.0	3.6	5.8	—0.2	3.2	2.3
Iowa Silver Mine	109	13	10	6.2	4.6	1.6	8.6	—2.4	5.7	2.3
Nebraska White Prize	103	13	10	6.2	5.1	1.1	8.1	—1.9	4.8	2.2
Pride of the North	102	12	9	6.0	0.6	5.4	4.6	+1.4	1.8	3.0
Minnesota No. 13	113	12	10	5.9	0.3	5.6	4.5	+1.4	1.0	2.9
White Cap	109	11	8	4.6	2.2	2.4	5.9	—1.3	3.3	2.2
University No. 3	110	12	9	5.5	2.9	2.6	6.3	—0.8	3.3	2.3
Average	107	12.5	9.5	5.9	2.6	3.3	6.4	—0.4	3.3	2.3

Variety	Fertilization first apparent on silks									Barren plants per 100	Plants with sterile tassels per 100
	Before pollen maximum		After pollen maximum		Before pollen begins		After pollen ceases		Number of days after silks appear		
	Per cent of plants	Days	Per cent of plants	Days	Per cent of plants	Days	Per cent of plants	Days			
(1)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
Reid's Yellow Dent	2	1.0	98	2.9	0	0	16	1.5	3.6	6	0
Hogue's Yellow Dent	0	0.0	100	3.6	0	0	10	1.9	3.6	3	0
Iowa Gold Mine	1	1.0	99	2.8	0	0	24	1.7	3.6	5	0
Leaming	1	1.0	99	2.5	0	0	14	3.2	3.5	5	0
Calico	1	1.0	99	2.8	0	0	33	2.1	3.5	5	0
Bloody Butcher	0	0.0	100	2.9	0	0	33	2.2	3.9	2	0
Boone County White	0	0.0	100	5.8	0	0	39	3.3	4.3	7	0
St. Charles White	0	0.0	100	3.2	0	0	11	2.6	3.8	4	0
Iowa Silver Mine	0	0.0	100	5.7	0	0	13	2.7	3.9	6	0
Nebraska White Prize	0	0.0	100	4.8	0	0	15	2.5	4.0	7	0
Pride of the North	6	2.3	94	2.1	0	0	9	1.0	4.1	2	8
Minnesota No. 13	9	1.4	91	1.2	0	0	15	1.5	4.1	0	0
White Cap	0	0.0	100	3.3	0	0	43	1.8	3.7	1	0
University No. 3	0	0.0	100	3.3	0	0	26	1.5	3.5	4	0
Average	1.4	0.5	98.6	3.3	0	0	21.5	2.1	3.8	4	0.5

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TABLE 7.—*Relationship between the shedding of pollen, silking, and fertilization of corn. 1915.*

Variety	Number of plants averaged	Pollination period for variety (days)		Number of days shedding pollen (individual plant average)					Pollen maximum before silks indicate fertilization (days)	Maximum length of silks (inches)
		Maximum length	More than 12% plants shedding pollen	Entire period	Before silks appear	After silks appear	Before fertilization is apparent	After fertilization is apparent		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Reid's Yellow Dent	120	13	11	5.9	0.3	5.6	3.9	2.0	0.8	2.8
Hogue's Yellow Dent	113	16	10	6.5	1.1	5.4	5.0	1.5	1.2	2.6
Iowa Gold Mine	117	14	10	5.6	0.9	4.7	4.1	1.5	0.6	2.3
Leaming	115	13	10	5.4	0.6	4.8	4.2	1.2	1.0	2.7
Calico	110	13	9	6.0	1.8	4.2	4.7	1.3	1.3	2.4
Bloody Butcher	113	14	11	5.9	2.0	3.9	4.6	1.3	1.2	2.2
Boone County White	105	16	12	6.8	2.5	4.3	6.1	0.7	2.4	2.0
St. Charles White	118	13	10	7.0	1.4	5.6	5.2	1.8	0.8	2.4
Iowa Silver Mine	116	14	11	6.7	1.2	5.5	5.3	1.4	1.3	2.5
Nebraska White Prize	107	18	14	7.5	1.6	5.9	5.4	2.1	1.4	2.5
Pride of the North	118	14	11	6.2	0.8	5.4	4.1	2.1	0.0	2.5
Minnesota No. 13	120	11	8	5.3	0.9	4.4	4.1	1.2	0.6	2.2
White Cap	117	13	10	6.3	0.8	5.5	4.3	2.0	0.2	2.4
University No. 3	117	12	9	6.4	1.9	4.5	5.2	1.2	0.7	2.2
Average	115	13.9	10.4	6.25	1.3	5.0	4.7	1.5	0.9	2.4

Variety	Fertilization first apparent on silks								Number of days after silks appear	Barren plants per 100	Plants with sterile tassels per 100
	Before pollen maximum		After pollen maximum		Before pollen begins		After pollen ceases				
	Per cent of plants	Days	Per cent of plants	Days	Per cent of plants	Days	Per cent of plants	Days			
(1)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
Reid's Yellow Dent	48	1.4	52	1.8	0	0	0	0	3.6	0	0
Hogue's Yellow Dent	42	0.9	58	2.7	0	0	0	0	3.9	6	1
Iowa Gold Mine	61	0.8	39	2.9	0	0	3	3	3.2	3	0
Leaming	45	0.6	55	2.4	0	0	0	0	3.6	4	0
Calico	45	0.6	55	2.9	0	0	0	0	2.9	7	2
Bloody Butcher	50	0.6	50	3.1	0	0	1	3	2.6	7	0
Boone County White	19	0.9	81	3.2	0	0	1	2	3.6	6	0
St. Charles White	48	1.1	52	2.5	0	0	2	2	3.8	0	0
Iowa Silver Mine	41	0.9	59	2.9	0	0	1	1	4.1	2	1
Nebraska White Prize	38	1.1	63	2.9	0	0	1	2	3.8	3	0
Pride of the North	68	0.9	32	1.8	0	0	0	0	3.3	1	0
Minnesota No. 13	52	0.4	48	1.7	0	0	1	2	3.2	0	0
White Cap	63	0.8	37	2.0	1	1	0	0	3.5	2	1
University No. 3	65	1.1	45	3.0	0	0	0	0	3.3	3	0
Average	49	0.9	52	2.6	0	0	0.7	1.0	3.5	3	0.4

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TABLE 8.—*Relationship between the shedding of pollen, silking, and fertilization of corn. Two-year average, 1914-1915.*

Variety	Number of plants averaged	Pollination period for variety (days)		Number of days shedding pollen (individual plant average)					Pollen maximum before silks indicate fertilization (days)	Maximum length of silks (inches)
		Maximum length	More than 12% plants shedding pollen	Entire period	Before silks appear	After silks appear	Before fertilization is apparent	After fertilization is apparent		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Reid's Yellow Dent	219	13.5	10.5	6.2	1.3	4.8	5.0	+1.2	1.5	2.5
Hogue's Yellow Dent	215	14.5	10.0	6.3	1.9	4.3	5.7	+0.6	2.4	2.3
Iowa Gold Mine	227	13.5	10.0	5.6	1.5	4.1	4.9	+0.7	1.7	2.1
Leaming	226	12.5	9.5	5.6	1.3	4.3	4.9	+0.7	1.7	2.4
Calico	219	12.5	9.0	5.8	2.1	3.7	5.3	+0.5	2.0	2.2
Bloody Butcher	223	13.5	10.5	5.8	2.1	3.7	5.4	+0.3	2.0	2.2
Boone County White	203	15.0	11.0	6.7	3.0	3.2	7.7	—1.0	4.1	2.0
St. Charles White	231	12.0	9.5	6.3	1.7	4.6	5.5	+0.8	2.0	2.3
Iowa Silver Mine	225	13.5	10.5	6.4	2.9	3.5	6.9	—0.5	3.5	2.4
Nebraska White Prize	210	15.5	12.0	6.8	3.3	3.5	6.7	+0.1	3.1	2.3
Pride of the North	220	13.0	10.0	6.1	0.7	5.4	4.3	+1.7	0.9	2.7
Minnesota No. 13	233	11.5	9.0	5.6	0.6	5.0	4.3	+1.3	0.8	2.5
White Cap	226	12.0	9.0	5.4	1.5	3.9	5.1	+0.3	1.7	2.3
University No. 3	227	12.0	9.0	5.9	2.4	3.5	5.7	+0.2	2.0	2.2
Average	222	13.1	9.9	6.0	1.9	4.1	5.5	+0.5	2.1	2.3

Variety	Fertilization first apparent on silks									Barren plants per 100	Plants with sterile tassels per 100
	Before pollen maximum		After pollen maximum		Before pollen begins		After pollen ceases		Number of days after silks appear		
	Per cent of plants	Days	Per cent of plants	Days	Per cent of plants	Days	Per cent of plants	Days			
(1)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
Reid's Yellow Dent	25	1.38	75	2.52	0	0	8.0	1.5	3.6	3.0	0.0
Hogue's Yellow Dent	21	.90	79	3.27	0	0	5.0	1.9	3.7	4.5	0.5
Iowa Gold Mine	31	.80	69	2.82	0	0	13.5	1.8	3.4	4.0	0.0
Leaming	23	.60	77	2.46	0	0	7.0	3.2	3.5	4.5	0.0
Calico	23	.60	77	2.83	0	0	16.5	2.1	3.2	6.0	1.0
Bloody Butcher	25	.60	75	2.97	0	0	17.0	2.2	3.2	4.5	0.0
Boone County White	9	.90	91	4.63	0	0	20.0	3.3	3.9	6.5	0.0
St. Charles White	24	1.10	76	2.96	0	0	6.5	2.5	3.8	2.0	0.0
Iowa Silver Mine	20	.90	80	4.66	0	0	7.0	2.6	4.0	4.0	0.5
Nebraska White Prize	19	1.10	81	4.06	0	0	8.0	2.5	3.9	5.0	0.0
Pride of the North	37	1.10	63	2.02	0	0	4.5	1.0	3.7	1.5	4.0
Minnesota No. 13	30	.55	70	1.37	0	0	8.0	1.5	3.6	0.0	0.0
White Cap	31	.80	69	2.95	0.5	1	21.5	1.8	3.6	1.5	0.5
University No. 3	32	1.10	68	3.21	0	0	13.0	1.5	3.4	3.5	0.0
Average	25	.89	75	3.05	0	0	11.1	2.1	3.6	3.6	0.5

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TABLE 9.—*Summary of the relationships between the shedding of pollen, silking, and fertilization of corn. 1914, 1915, and 1920.*

	1914	1915	1920	Av.
	Days	*Days*	*Days*	*Days*
Av. number of days after tassel is visible until—				
a. Shedding of pollen begins	5.2	7.0	6.9	6.4
b. Tassel is entirely out	5.7	5.8	7.5	6.3
c. Silks first show	7.8	8.3	8.9	8.3
d. Pollen is shed at maximum rate	8.2	10.8	10.4	9.8
e. Silks attain maximum length	9.9	10.5	11.8	10.7
f. Silks show fertilization	11.6	11.7	12.7	12.0
g. Tassel ceases to shed pollen	11.1	13.2	13.9	12.7
Av. number of days after pollen begins to shed until—				
a. Silks first appear	2.6	1.3	2.0	2.0
b. Pollen is shed at maximum rate	3.0	3.8	3.5	3.4
c. Silks show fertilization	6.4	4.7	5.8	5.6
d. Pollen ceases to shed	5.9	6.2	7.0	6.4
Av. maximum length attained by silks (inches)	2.3	2.4	3.4	2.7
Av. length of pollination period for variety in which—				
4 per cent or more plants shed pollen (days)	12.5	13.8	.....	13.1
12 per cent or more plants shed pollen (days)	9.5	10.4	.....	10.0

Fourteen varieties were observed and averaged for the years 1914 and 1915; and nine varieties were observed and averaged for 1920.

In 1914, 1,498 normally developed plants were observed for pollination relationship and averaged; in 1915, 1,606 plants were so observed; and in 1920, 67 such plants were observed.

the pollen which fertilizes the corn falls upon the silks during a three-day period centering upon the maximum shedding of pollen by the same plant. Seasonal climatic conditions influence the time elapsing between the various flowering stages of the corn plant. Favorable conditions at the time of the flowering period, as existed in 1915, caused the silks to appear 1.3 days earlier in relation to the initial shedding of pollen than was the case in the somewhat drier year of 1914. Unfavorable conditions tend to delay the development of the ears more than that of the tassels. Under adverse conditions, the extension of the pollination period for a cornfield by the variability of its individual plants is an important factor in reducing the number of otherwise imperfectly fertilized ears.

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As an average for the two years 1914 and 1915, the average duration of shedding pollen by the individual plant was 6.0 days. The silks first appeared 1.9 days after pollen was being shed, and fertilization first became apparent by the characteristic change in appearance of silks 3.6 days later, or 0.6 of a day before the shedding of pollen ceased. The pollen was being shed at the maximum rate 2.1 days before fertilization was apparent by the change in appearance of the silks. Allowing 2.5 days for the fertilization to become manifest on the silks, it appears that the fertilizing pollen fell upon the silks within a day of the time when pollen was dropping at its maximum rate.

TABLE 10.—*Condition of silks at stated intervals after pollination. Hogue's Yellow Dent corn, 1921.*

Hours after applying pollen at 5 P. M.	Condition of exposed portion of silks					
	General slight yellowish discoloration	Few silks darkly discolored	20 per cent of silks darkly discolored	50 per cent of silks darkly discolored	75 per cent of silks darkly discolored	100 per ct. of silks darkly discolored
	Per cent of plants in condition indicated					
20	3	0	0	0	0	0
24	25	0	0	0	0	0
36	26	38	2	11	0	0
42	17	13	20	15	2	0
48	14	12	47	15	8	0
60	9	10	51	12	18	0
67	3	10	38	27	19	3
72	.....	3	28	42	22	5
91	.....	.....	4	21	22	53
98	.....	.....	1	6	18	75
114	.....	.....	.....	1	9	90
120	.....	.....	.....	.....	2	98
138	.....	.....	.....	.....	.....	100

The data for columns 1 to 20 of Tables 6 and 7 are based

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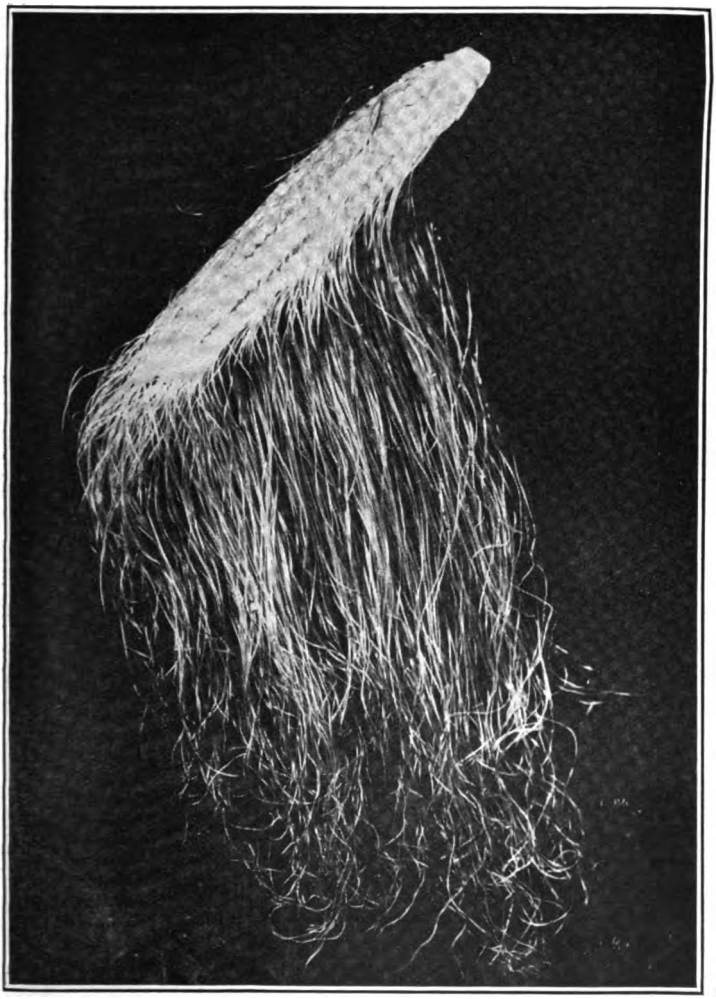

FIG. 5.--An ear of corn at silking time. Every kernel has its own silk and must be fertilized separately. In the process of fertilization, pollen falling on the silk germinates and grows a pollen tube thru the silk to the kernel, to which it conducts the two sperm nuclei. One of these nuclei fuses with the egg nucleus to form the initial embryo nucleus, and the other with the two polar nuclei, forming the initial endosperm nucleus. This entire process has been found to be completed within approximately 24 hours' time. Fertilization is reflected in the discoloration and drying of the silks in from 42 to 72 hours after pollination.

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was only 6.0 days, the spread of time between the initial and final shedding of pollen by different plants within the variety equaled 13.1 days. This is due to a number of causes, including strain differences, delayed development, and soil inequalities. The average spread of time for the various varieties in which 12 per cent or more of the plants were shedding pollen equaled 9.9 days.

As a grand average for the three years, 1914, 1915, and 1920, the entire pollination period for a plant was 6.3 days. The silk first appeared two days after the dropping of the pollen began. Pollen was shed at the maximum rate 3.4 days after it began, which is practically midway in the pollinating period of the plant. The silks showed fertilization 5.6 days after the pollen began dropping, which is practically a day before it ceased. This suggests that the average plant in the average year is shedding pollen at approximately the maximum rate at the time when its ear is pollinated, thus providing ample opportunity for self-fertilization. The average length of time in these three years during which cornfields shed their pollen was 13.1 days, and 12 per cent or more of the plants in these fields shed pollen for a period of ten days.

AMOUNT OF SELF-FERTILIZATION OCCURRING NORMALLY IN A CORNFIELD

In the year 1915, 40 plants of Nebraska White Prize corn were grown, distributed systematically 60 hills apart in a field of pure Hogue's Yellow Dent corn. Both varieties had identical flowering periods. The per cent of self-fertilization occurring in the Nebraska White Prize corn could be determined after maturity by the per cent of kernels on the Nebraska White Prize ears which were pure white. As a result of xenia the kernels fertilized by other plants were yellow. Upon maturity all of the kernels produced by the Nebraska White Prize plants were separated into four groups: (1) Those distinctly showing a yellow cast, which were unquestionably cross-fertilized; (2) those which were pure white and without a doubt self-fertilized; (3) those which showed only a very faint yellowish tinge and were doubtful as to purity; and (4) those kernels which had very light yellow caps and whose verification was desired.

In the following year, 1916, the last three groups were planted in the field and their pure or hybrid nature established by inbreeding 50 plants of each. (Table 11.) By this test the 1.05 per cent apparently pure white kernels were reduced to 0.7 per cent pure white. All of the kernels in the somewhat doubt-

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ful groups (3 and 4) proved to be hybrid. Thus it was established that only 0.7 per cent of the kernels of the Nebraska White Prize corn were self-fertilized. Natural field pollination under our conditions appears to be very effective in preventing self-fertilization.

TABLE 11.—*Amount of self-fertilization occurring with Nebraska White Prize corn plants grown scatteringly in a field of Hogue's Yellow Dent corn.*[1] *1915.*

Classification of kernels	Per cent kernels based on eye separation	Per cent kernels after verifying those doubtful by planting and inbreeding
	Per cent	*Per cent*
Total kernels harvested	100.00	.....
Distinctly yellow (hybrid)	90.40	.....
White or faintly yellow—		
Apparently pure white	1.05	0.70
Apparently hybrid	3.80	3.80
Doubtful kernels proved hybrid	4.70	4.70
Verified per cent of self-fertilization	.....	0.70

[1]The initial flowering period of both varieties fell on the same dates.

EFFECT UPON SEED VALUE OF PREVENTING THE NORMAL AMOUNT OF SELF-FERTILIZATION OCCURRING IN A FIELD OF CORN

During the eight years 1912 to 1917 and 1920 and 1921, a comparative yield test was made of Nebraska White Prize seed corn which had been produced on detasseled plants as opposed to seed from plants not having the tassels removed. In the seed plat, planted to ordinary wind fertilized corn, 8 or more alternating rows were detasseled each year, and the 100 best developed ears were saved from both the detasseled and the undetasseled rows to furnish seed for the following year's yield test. The test plats consisted of single rows 16 rods in length, and were replicated from 6 to 12 times each year. The air-dry

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letasseling upon the seed value of corn (Nebraska White Prize). Eight years, 1912-1917 and 1920-1921.

	Yield of grain per acre								
	1912	1913	1914	1915	1916	1917	1920	1921	Average
	Bushels (2)	*Bushels* (3)	*Bushels* (4)	*Bushels* (5)	*Bushels* (6)	*Bushels* (7)	*Bushels* (8)	*Bushels* (9)	*Bushels* (10)
....	51.6	8.1	51.8	72.9	34.9	50.6	54.0	65.0	48.6
....	54.4	8.6	52.8	69.2	33.3	50.8	51.0	66.3	48.3
....	10	10	12	12	8	8	6	6	

Summary of plant characteristics during 6 years, 1914-1917 and 1920 and 1921

Ear height	Date tasseling	Date ripe	Lodging	Two-eared stalks per 100 plants	Barren plants per 100	Suckers per 100 plants	Shrinkage of ear corn	Shelling per cent
Inches (12)	(13)	(14)	*Per cent* (15)	(16)	(17)	(18)	*Per cent* (19)	*Per cent* (20)
49	8/1	9/22	27	4	4	13	5.4	82.0
48	8/1	9/22	28	6	4	13	5.5	81.9

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actually occurs under our ordinary field conditions is negligible and that no material advantage results from selecting seed from detasseled rows and thereby assuring the prevention of all self-fertilization.

Incidentally the yields were determined separately for the detasseled and not detasseled rows in the seed plat for the purpose of determining the immediate effect of detasseling upon the current crop. As an average for the eight years (Table 13), the plats from which all of the tassels were removed yielded 43.6 bushels per acre as compared with 42.9 bushels for the normal corn. The tassels were removed at their first appearance by means of an upward pull which disjointed them without molesting the leaves.

TABLE 13.—*Immediate effect of detasseling upon the current grain yield of the detasseled plants. (Nebraska White Prize.) Eight years, 1912-1917 and 1920-1921.*

Treatment	Yield of grain per acre								
	1912	1913	1914	1915	1916	1917	1920	1921	Average
(1)	*Bu.* (2)	*Bu.* (3)	*Bu.* (4)	*Bu.* (5)	*Bu.* (6)	*Bu.* (7)	*Bu.* (8)	*Bu.* (9)	*Bu.* (10)
Detasseled	51.6	10.9	38.2	68.1	39.9	41.5	43.4	55.1	43.6
Not detasseled	54.4	10.1	38.0	71.7	35.0	37.9	43.6	52.3	42.9
Number of plats averaged	8	18	19	8	8	8	8	8	

ELEMENTAL STRAINS IN CORN AND THEIR HYBRIDIZATION

SIGNIFICANCE OF ELEMENTAL STRAINS

An ordinary commercial variety of corn is very complex in its inheritance. We may think of such a variety as having for its basis a large number of elemental strains or "pure lines" which differ from each other in some more or less important structural or physiological characteristic. These elemental strains do not occur in the variety as a mere mechanical mixture, but rather as natural hybrids due to chance wind pollination. The characteristics transmitted by these elemental strains to their hybrid offspring is in accordance with the principles of Mendelian inheritance. They are represented in the germ plasm (chromosomes of the reproductive cells) in the form of Mendelian factors or units of inheritance. All inheritance is transmitted thru the chromosomes, of which field corn is believed to

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have uniformly ten in each egg or sperm cell. Upon hybridization these factors mingle and remain together in all the vegetative cells until shortly before the formation of eggs and sperms when they are segregated as units or groups, forming new combinations, part of which were derived from each of the parent plants.

In commercial varieties, these units of heredity undergo chance rearrangement at each fertilization and practically no

1 2 3 4

FIG. 6.—Effect of inbreeding and hybridizing Hogue's Yellow Dent corn. No. 1, typical Hogue's Yellow Dent plant. Nos. 2 and 4, typical elemental strains or pure line plants produced from Hogue's Yellow Dent (No. 1) by six years' continuous self-fertilization. No. 3, first generation hybrid plant grown from seed produced on No. 2 fertilized with pollen from No. 4.

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all eggs and sperms produced by the offspring will have nuclei which carry the same Mendelian factors. This purified condition of the germ plasm, in which all zygotes, i. e., eggs and sperms, are alike, is called homozygous as opposed to the hybrid or heterozygous condition where two unlike zygotes have united and where many different kinds of zygotes may be formed by segregation of the factors derived from the parents.

The elemental strains differ in such visible physical and physiological characters as height of stalk, diameter of stalk, leaf area, leaf width, erectness of leaves, suckering tendency, brace root development, lodge resistance, firing of leaves, firing of tassels, sterility of tassels, barrenness of ears, stalk and leaf color, grain color, cob color, silk color, anther color, tassel conformation, shank development, ear type, kernel type, grain yield, disease resistance, and earliness of maturity.

Many heritable variations and gradations of these and other plant characteristics are found in innumerable hybrid combinations in an ordinary corn variety. The particular chance combination of factors or groups of factors upon fertilization of the egg determines the exact nature of many of the individual plant characters as well as of the complete assemblage of characters comprising the plant in its entirety.

The more closely any variety, or individual corn grower's subvariety, has been selected for trueness to plant or ear type, thru prolonged continuous selection, the fewer will be the number of elemental strains represented in its composition. Accordingly, the greater will be the likelihood under ordinary field conditions of some identical factors of inheritance from both parents uniting in the process of fertilization. Whenever these identical factors represent growth or vigor or production characters in the offspring, then there is likelihood of reduction in the size, vigor, and production of the individual offspring so constituted.

When all of the growth factors in both parents are identical, as in an artificially reduced "pure line," a marked degree of reduction in vigor, growth, and production results. Since there is variation in the degree of growth, vigor, or production represented in the corresponding Mendelian factors, much variation occurs in the vigor and productiveness of the different distinct elemental strains. In turn, when certain pairs of elemental strains are hybridized by controlled fertilization, their lines of immediate first generation offspring will differ from each other in vigor, growth, and production, in accordance with the effect

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produced by the particular combination of Mendelian factors in each hybrid.

Tho perhaps possible, no elemental strain of corn has yet been found by the Nebraska Experiment Station, or to our knowledge has been reported elsewhere, which is as vigorous or productive as the original variety from which it was derived by repeated self-fertilization. On the other hand, a large range of degrees of productivity is found in first generation hybrids between various elemental strains, ranging from no increase to a somewhat greater productivity than that of the original variety. Our results and those of a number of other investigators would seem to justify more extended investigation of the practical possibilities of wholesale elimination of undesirable Mendelian factors and the recombination of those factors which result in superior production. Methods and results along this line at the Nebraska Experiment Station are as follows:

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PRODUCTION OF ELEMENTAL STRAINS

Two standard eastern Nebraska varieties of corn were used, Hogue's Yellow Dent and Nebraska White Prize. Inbreeding work with the former variety began in 1908 and with the latter in 1912. Ear-to-row strains were used as the foundation stock.

TECHNIQUE OF ARTIFICIAL POLLINATION

The procedure in self-fertilization is to pollinate the silks of an ear with pollen produced by the tassel of the same plant. To accomplish this without contamination by foreign pollen, good quality manilla paper bags are inverted over the tassel and tied at its base a few days before the pollen is expected to be used, which usually is about the time when the tassel begins to shed pollen. This frequently is facilitated by removing the upper leaf. The enclosing of leaves in the bag is avoided, as the moisture accompanying transpiration may cause deterioration of the pollen. Whenever the ear shoot has made considerable growth, but a few days before the silks emerge, a paper bag

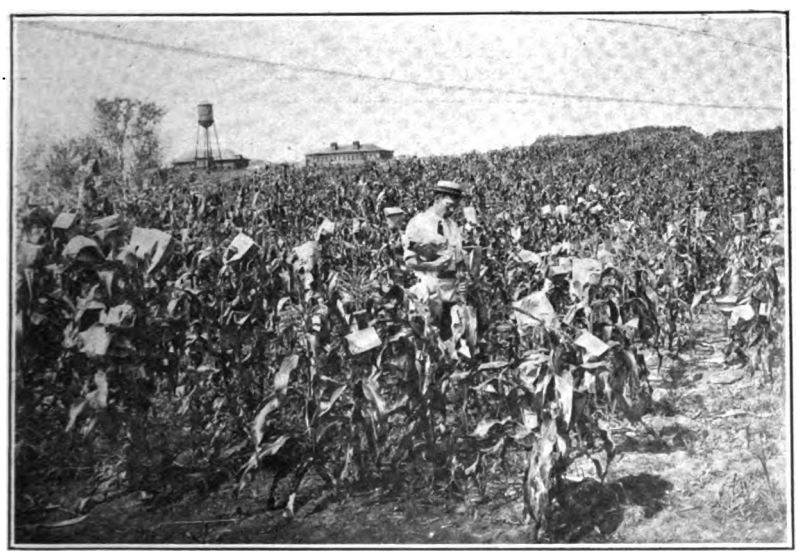

FIG. 8.— Inbreeding and crossbreeding pure lines of Hogue's Yellow Dent corn. The corn in this illustration may be compared for size with the original Hogue's Yellow Dent corn in figure 7, from which it was derived by six years of inbreeding.

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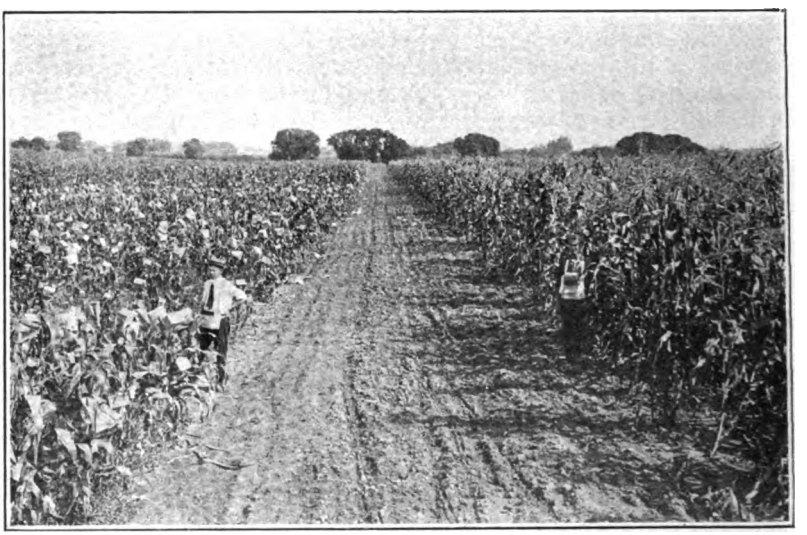

FIG. 9.—The artificial corn breeding plats at the left contain 140 distinct inbred strains of Hogue's Yellow Dent and Nebraska White Prize corn. The corn to the right is standard Hogue's Yellow Dent.

is placed over the ear and closely tied with cord at its base. This excludes foreign pollen, which might otherwise fertilize the ear. The ears may be pollinated as soon as the silks are fully out. The presence of silks can usually be felt by the operator thru the bag. The presence of pollen in the bag over the tassel can readily be heard if the bag is given a gentle shaking. Transfer of the pollen to the silk is effected as follows: The operator loosens the cord holding the bag over the ear; he then moistens his hands in 10 per cent alcohol, to sterilize any foreign

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FIG. 10.—Elemental strains of Hogue's Yellow Dent corn after six years of inbreeding. The almost absolute uniformity of plants within each of the strains is suggested in the picture. Many such distinct strains form the foundation of an ordinary corn variety, in which they occur in hybrid combinations.

several weeks, until all possible danger of chance fertilization of belated silks is past. The source of pollen is indicated with hardware black pencil, on the bag, which serves for temporary identification. As soon after pollination as is convenient, fully marked identification tags are tied to each ear. Rain is sometimes a very disturbing element and may necessitate the renewal of bags over the tassels. Very satisfactory modifications of the above procedure are possible.

LIFE OF POLLEN

In controlled pollination it is desirable to know how long pollen will retain viability after being shed. It is necessary that any foreign pollen which may have lodged upon the tassel at the time of covering should have lost its viability before the pollen is used in fertilization. For the purpose of approximating the life of pollen, the following tests were made: One hundred ear shoots of Hogue's Yellow Dent corn were bagged to exclude pollen. A quantity of pollen was shaken into a bag from a large number of plants. This was immediately stored in a dry building of 75°-85° F. At intervals of 10, 24, 30, 34, 38, 51,

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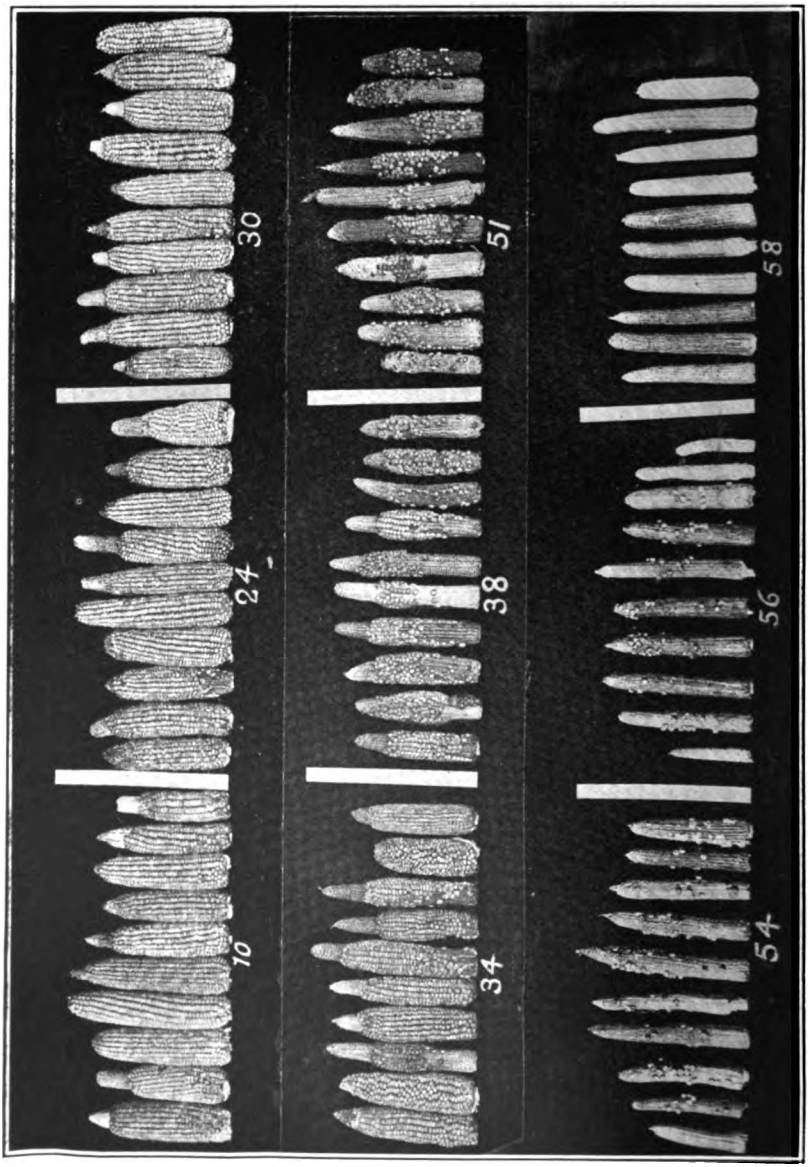

FIG. 11.—Life of pollen. The number of hours elapsing under rather favorable conditions between the time of gathering and the time of applying pollen is shown by the figures beneath each group of ten ears. The life of pollen varies under different conditions, commonly being of shorter duration in the field than is here indicated.

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54, 56, and 58 hours after collecting the pollen, ten of the covered ears, having abundant silk development, were fertilized with this pollen. The relative viability of pollen at various ages is illustrated by the number of kernels fertilized on the ears shown in figure No. 11. Fertilization was very poor at the end of 51 hours and failed after 58 hours.

In 1920, fresh pollen was collected at 7 A. M. from 40 tassels and was well mixed. This was immediately divided into 10 paper bags which were tied to the tops of corn plants in the cornfield, where they remained until used. The temperature range was from 75° F. to 100° F. and the mean relative humidity ranged from 30 to 70 per cent. Ears pollinated with this pollen 10 and 15 hours after it was collected showed good fertilization; but the pollen had practically lost its viability at the end of 24 hours. Thus it may be inferred that pollen kept under such intermediate conditions will have lost its viability at the end of 20 to 60 hours after shedding.

LIFE OF SILKS

The life of the unfertilized silk is seldom a problem in experiments involving the artificial fertilization of corn. Control tests have indicated that silks are receptive to pollination before they have emerged from the husk, and for a period of two weeks thereafter. The earliest effective application of pollen in some instances necessitated opening the husks three or four inches to reach the silks. In other cases of delayed yet effective pollination silks were exposed for a length of twelve inches. Silks continue to grow in length for some time if pollen is withheld. Such silks may be cut off to a short length and yet be successfully pollinated. In controlled fertilization experiments which necessitate covering the young ears, it is important to keep them covered for some time after applying the pollen, in order to avoid the chance pollination of late receptive silks.

Dr. E. C. Miller of the Kansas Agricultural Experiment Station has found by means of histological studies that fertilization of the kernel is effected within a period of about 24 hours after applying pollen to the silk. Thru similar studies, Dr. Paul Weatherwax of the University of Georgia estimates the lapse of time between pollination and fecundation at about twenty-five hours. Germination of the pollen on the silk is rather rapid. In our tests regarding this, the tip ends of the ear shoots were sterilized in alcohol six hours after pollination, and were cut off a short distance below the end of the husks in order to completely remove the portion of the silks to which the pollen had been applied. The ears were kept covered to exclude further

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pollination. Almost perfect fertilization of the ears resulted, indicating rapid development of the pollen tube. Following fertilization, the silk shrivels up at its base, thus cutting off further sap supply. Thereupon the silk withers and dies, the first reliable external evidence of which is observed on the silks in from forty to seventy hours after pollination.

HOGUE'S YELLOW DENT (CLASS IX) PURE LINES AND HYBRIDS

PURE LINES

These pure lines were derived from the 1907 progeny of the four highest yielding ear-to-row strains determined in a two-year (1906-1907) test with 204 individual ears of Hogue's Yellow Dent corn. These four ear-to-row strains were assigned the stock numbers 5, 6, 15, and 17. Three well-developed ears were selected from each of these four strains and planted individually in small partially isolated increase plats, in 1908, constituting twelve inbred strains. Beginning with 1909, single ears from each of the strains were planted in adjacent rows for controlled self-fertilization. In 1911 four of the inbred strains had become sterile and another was lost in 1915. Figure 12 shows representative plants of the eight surviving strains in 1915. The plant to the left is typical of the original variety, while the others from left to right are strains Nos. 1, 2, 4, 5, 8, 9, 10, 12. (Table No. 14.) Typical ears borne by the strains in 1916 are shown in figure 13.

Table No. 14 gives the comparative yields and plant characters (1916) for seven strains, and for the original Hogue's Yellow Dent. Considerable variation is seen to exist in the productivity of different strains, tho the best one yielded only 41 per cent as much as the original. Comparing the average of the seven inbred strains with the original Hogue's Yellow Dent corn: (1) The date of tasseling was one day earlier; (2) the date of ripening was three days earlier; (3) the stalk height was 63 per cent; (4) the ear height was 53 per cent; (5) the leaf area was 56 per cent; and (6) the grain yield was 27 per cent as large. Yield tests of the individual strains have not been made in other years, tho they have been compared in composite with the original each year, beginning with 1911. The annual composite results are included in Table 25 on page 72. During the years 1911, 1912, 1913, 1914, 1915, 1916, and 1917 the pure lines yielded respectively 47, 35, 13, 23, 34, 28, and 30 per cent as much grain per acre as the original corn.

In 1914, after five years of selfing, these strains had apparently all attained the pure elemental state, since their progeny

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arison of pure lines of Hogue's Yellow Dent corn with the original. 1916.

e l-	Date ripe	Ear height	Stalk height	Leaf area per plant	Suckers per 100 plants	Barren plants per 100	2-eared stalks per 100 plants	Lodging	Shrinkage of ear corn	Per cent shelled corn	Yield per acre
		Feet	*Feet*	*Sq. in.*				*Per ct.*	*Per cent*	*Per cent*	*Bu.*
	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	9/18	1.5	3.8	649	4	1	6	12	2.1	77.6	14.5
	9/18	1.5	3.8	796	12	1	4	1	1.6	77.1	8.0
	9/18	1.6	3.7	632	10	14	2	1	3.1	73.0	2.3
	9/17	1.8	4.5	745	4	8	0	95	5.4	56.1	3.1
	9/17	1.8	4.4	651	2	1	5	9	1.2	85.0	10.8
	9/17	1.7	4.5	687	9	12	6	18	1.3	84.9	15.4
	9/13	1.8	4.6	700	1	1	1	12	2.1	77.4	14.8
	9/17	1.6	4.1	694	6	5	3	21	2.4	75.8	9.8
	9/20	3.0	6.5	1,244	48	8	2	49	2.8	81.0	37.5

been corrected according to check plats of the original Hogue's Yellow Dent corn so as to be ta for hybrids of these pure lines reported in Table 16.

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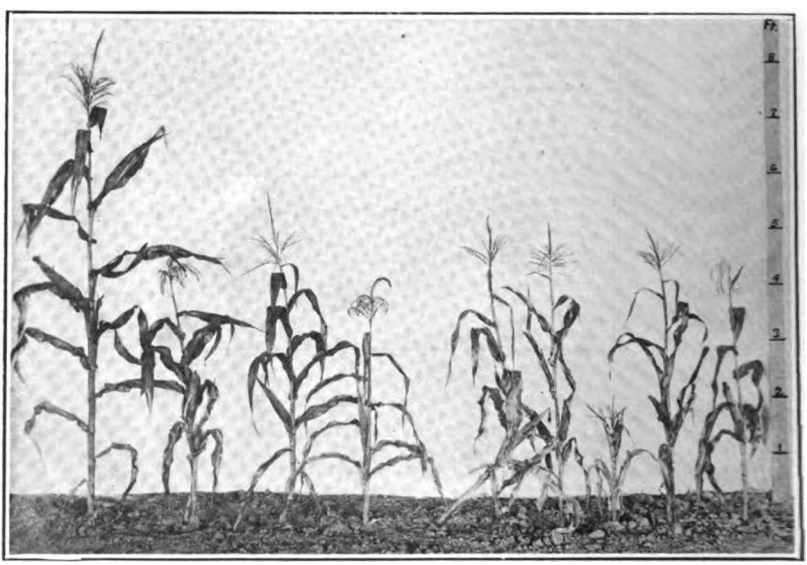
appeared to be uniform in all characteristics. Further proof of this pure (homozygous) condition was had in 1916. Several ears of each strain were fertilized with pollen from sister plants of the same strain in 1915. These were planted in 1916 in comparison with the self-fertilized seed. The sister bred corn was no more vigorous than the inbred and could not be distinguished from it. This lack of increased vigor following sister breeding is evidence of purity as to Mendelian factors. All plants of each strain appeared to have identical germ plasm and all plants were similar except as affected by slight environmental differences.



Strain No. Orig. 1 2 4 5 8 9 10 12

FIG. 12.—Typical plant of Hogue's Yellow Dent corn at left. At right, typical plants of eight distinct pure lines of the same variety after six years of self-fertilization. When used in hybridization each

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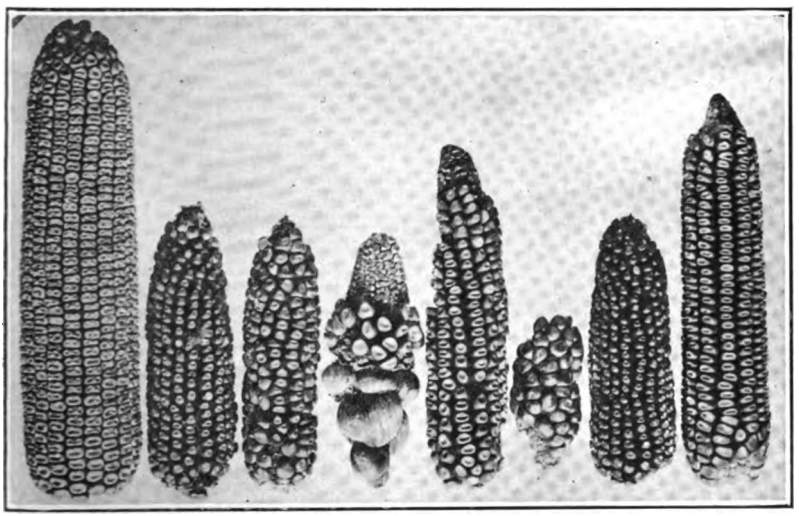
means of artificial control in order to avoid contamination. This is accomplished by transferring the pollen of one strain to the ear of another strain in the same manner as has been described on page 43 for the production of pure lines. When the resultant seed is planted, the first generation (F_1) hybrid plants



Strain No.

Orig. 8 2 5 1 4 10 12

FIG. 13.—Typical ear of Hogue's Yellow Dent corn at left. At right, typical ears of seven distinct pure lines of the same variety after six years of self-fertilization. The yields for these strains in 1916 are given in Table 14, and were respectively: Original, 37.5 bu.; 8, 10.8 bu.; 2, 8.0 bu.; 5, 3.1 bu.; 1, 14.5 bu.; 4, 2.3 bu.; 10, 15.4 bu.; and 12, 14.8 bu. per acre.

are produced. In figure 14 are shown representative plants of each of ten different F_1 hybrid combinations among the elemental strains shown in figure 12. Many other combinations of these seven strains have been grown and all showed increased vigor except the cross between strains 8 and 10. These two strains, altho originating from entirely different stock, do not differ materially in any visible character except in color of the midrib of the leaf and leaf sheath. Strain No. 10 has an orange-colored midrib, while No. 8 has a green midrib. It is likely that they are nearly identical in the Mendelian factors associated with vigor of growth. No extensive detailed study has been

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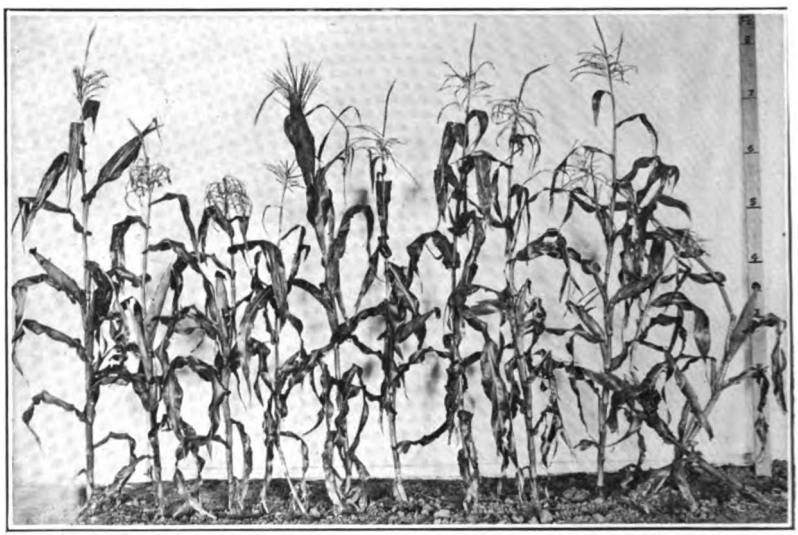
made of the Mendelian behavior of the various plant characters. However, the crooked stalk of strain 5 (fig. 12) is dominant in all of its F_1 hybrids (hybrids Nos. 12×5 and 10×5, fig. 14), and in the second generation (F_2) it breaks up in the normal F_2 ratio. The orange midrib of strain No. 10 is recessive in its F_1



Male parent:	12	1	10	10	2	2	12	10	5	5
Female parent:	4	4	8	9	8	12	10	2	12	10

FIG. 14.—Typical plant of Hogue's Yellow Dent corn at left and typical plants of ten first generation hybrids between some of the inbred strains shown in figure 12. The numbers below the plants show which of the strains in figure 12 were crossed. The grain yields of eight of these hybrids are given in Table 15 for four years in comparison with the original Hogue's Yellow Dent. Photograph taken in 1915.

hybrids, which break up in the simple Mendelian ratios in later generations. For example, comparing the first and second generations of the hybrid No. 2×10 (Table 16), all of the first generation plants had green midribs; while out of a total of 351 second generation hybrid plants observed, 78 had orange and 273 green colored midribs. This amounts to an actual 22 per cent orange colored midribs, whereas the theoretical number for a simple unit character should be 25 per cent.

Only eight F_1 hybrids between elemental strains reported

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-*Comparison of first generation hybrids of Hogue's Yellow Dent corn pure lines with the original variety. 1913, 1915, 1916, and 1917.*[1]

:e :el- :	Date ripe	Ear height	Stalk height	Suckers per 100 plants	Barren plants per 100	2-eared stalks per 100 plants	Lodging	Leaf area per plant	Shrinkage of ear corn	Shelling per cent	Bushels per acre of shelled corn					
											1913	1915	1916	1917	2-year average 1915-'16	4-year average
	(3)	*Feet* (4)	*Feet* (5)	(6)	(7)	(8)	*Per cent* (9)	*Sq. in.* (10)	*Per cent* (11)	*Per cent* (12)	*Bu.* (13)	*Bu.* (14)	*Bu.* (15)	*Bu.* (16)	*Bu.* (17)	*Bu.* (18)
3	9/19	2.8	6.5	41	1	23	23	900	2.3	83.1	22.0	61.9	38.8	60.6	50.3	45.8
3	9 19	2.7	6.3	68	2	35	10	1,003	2.5	85.2	26.8	64.8	53.2	41.6	59.0	46.6
6	9/23	3.2	7.5	0	1	28	39	1,112	4.8	81.5	22.8	69.5	44.6	48.5	57.0	46.4
6	9/22	3.0	7.1	72	2	41	8	968	5.2	90.2	20.1	71.3	66.2	51.9	68.7	52.4
7	9/23	3.3	7.3	27	2	40	9	1,070	4.2	87.2	21.9	73.6	58.0	59.4	65.8	53.2
5	9/21	3.1	7.3	4	0	37	29	925	3.9	86.6	22.7	57.9	51.5	53.6	54.7	46.4
7	9/22	3.2	7.1	2	5	31	56	1,104	4.9	86.9	24.2	61.0	43.3	51.0	52.1	44.9
6	9/23	3.2	7.5	72	0	41	18	996	3.2	90.1	25.6	75.4	58.2	45.2	66.8	51.1
..	9/21	3.1	7.1	36	2	34	24	1,010	3.9	86.3	23.3	66.9	51.7	51.5	59.3	48.3
8	9/23	3.3	7.5	60	4	25	29	1,236	7.3	83.1	11.4	73.1	34.5	46.0	53.8	41.2

too limited for a yield test of the individual crosses in 1914, due to the drouth in 1913. All data except yields are the average for ıly. Most of the records were not kept in 1913 and 1917.

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in Table 14 have been grown continuously thru a period of four years, 1913-1917. The results with these are shown in Table 15. As a four-year average for the eight hybrids, the yield of the original corn was exceeded by 17 per cent, while the highest yielding combination (12x2) yielded 29 per cent more grain than the original variety. In this connection attention may be called to the fact that the original Hogue's Yellow Dent has never been subjected to any degree of close breeding and is one of the highest yielding varieties ever grown at the Experiment Station. Detailed notes were taken for some of the plant characters in addition to the yield during 1915 and 1916. Compared with the original the eight hybrids ripened two days earlier on an average, were four inches shorter, and had 24 suckers and 2 barren stalks fewer per 100 plants. The leaf area was 13 per cent smaller, the shelling percentage 4 per cent higher, and the grain yield 10 per cent greater.

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A COMPARISON OF FIRST, SECOND, AND THIRD GENERATION PURE LINE HYBRIDS

In 1915 several F_1 plants in each of the eight combinations shown in Table 16 were fertilized with composite pollen of 15 sister plants, in order to produce seed for second generation (F_2) hybrid plants to be tested in 1916. In 1916, F_2 hybrid seed was again produced in the same manner, and third generation (F_3) hybrid seed was similarly produced from F_2 plants. First generation hybrid seed was produced anew each year, for comparison. The comparative 1916 results for the individual first and second generation hybrids are shown in Table 16, in contrast with the average results for the pure lines and the original corn. The original corn yielded 37.5 bushels per acre; the seven pure lines averaged 9.8 bushels; the eight first generation hybrids averaged 51.7 bushels; and the second generation hybrids 25.1 bushels per acre. Thus the F_1 crop yielded 138 per cent as much, the F_2 crop 67 per cent as much, and the pure lines 26 per cent as much as the original variety from which they were produced.

The increased degree of homozygosity due to Mendelian segregation and recombination of parental factors would account for the reduction in yield of the second generation plants, which is nearly in accordance with expectancy in a hybrid population in which the factors represented were all derived from two homozygous individuals.

In 1917, F_1, F_2, and F_3 pure line hybrids were available for comparison. (Table 17.) The original seed yielded 46 bushels, the F_1 averaged 51.5 bushels, the F_2 29.4 bushels, and the F_3 25.6 bushels per acre. This extreme reduction in yield of the F_2 and F_3 crop below the yields of the F_1 and the original variety is evidence to show that, in any application of the principles of corn improvement thru crossing two pure lines, it is essential to avoid selecting seed from the hybrid progeny. An experiment is under way in which seed of a large number of elemental strains are mixed to be grown thereafter as a variety without further controlled inbreeding and hybridization. By mixing a large number of strains, the chance of union of like gametes is reduced and when enough strains are used will become small, as in ordinary commercial varieties. At the same time, advantage would be taken of the process of weeding out inferior strains thru inbreeding.

The two years' results with F_1 and F_2 crop are summarized in Table 18 and show respective yields of 52.2 and 27.8 bushels per acre in comparison with 41.7 bushels for the original corn.

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TABLE 16.—*Comparison of first and second generation hybrids of pure lines of Hogue's Yellow Dent corn with the original variety. 1916.*

Description	Date tasseling	Date ripe	Ear height	Stalk height	Leaf area per plant	Suckers per 100 plants	Barren plants per 100	Two-eared stalks per 100 plants	Lodging	Shrinkage of ear corn	Shelling per cent	Yield per acre
			Feet	*Feet*	*Sq. in.*				*Per cent*	*Per cent*	*Per cent*	*Bushels*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
4 × 12 F_1	7/18	9/18	3.0	6.0	879	38	5	1	38	1.5	80.0	38.8
F_2	7/18	9/16	2.7	5.7	813	17	12	2	9	1.6	75.6	21.6
Difference	0	2	-0.3	—0.3	—66	—21	+7	+1	—29	+0.1	+4.4	—17.2
4 × 1 F_1	7/17	9/16	2.7	5.9	1,027	82	4	1	16	2.3	84.3	53.2
F_2	7/16	9/15	2.7	5.7	946	60	12	5	7	1.7	79.6	31.4
Difference	1	1	0.0	—0.2	—81	—22	+8	+4	—9	—0.6	—4.7	—21.8
12 × 5 F_1	7/20	9/20	3.2	6.7	1,151	1	2	0	52	2.6	80.8	44.6
F_2	7/19	9/16	3.0	6.2	980	3	15	0	47	3.5	67.5	15.9
Difference	1	4	-0.2	— 0.5	—171	+2	+13	0	—5	+0.9	—13.3	—28.7
8 × 2 F_1	7/19	9/18	2.7	6.5	1,008	72	2	0	11	2.6	90.6	66.2
F_2	7/25	9/21	2.6	4.7	979	41	5	6	42	2.9	87.3	38.3
Difference	+6	+3	— 0.1	—1.8	—29	—31	+3	+6	+31	+0.3	—3.3	—27.9
12 × 2 F_1	7/20	9/20	3.5	6.7	1,031	38	2	2	8	2.2	87.2	58
F_2	7/20	9/15	2.7	4.7	916	23	5	7	23	3.2	80.8	28
Difference	0	-5	—0.8	—2.0	—115	—15	+3	+5	+15	+1.0	—6.4	—30
10 × 12 F_1	7/17	9/15	3.2	6.7	930	3	1	1	54	2.3	85.6	51.5
F_2	7/19	9/15	2.5	5.7	933	1	8	1	79	2.3	79.6	24.1
Difference	+2	0	—0.7	—1.0	+3	—2	+7	0	+25	0	—6.0	—27.4
10 × 5 F_1	7/22	9/20	3.3	6.3	1,185	1	5	1	92	2.5	86.0	43.3
F_2	7/22	9/15	2.5	5.7	1,098	0	13	1	82	4.1	79.1	17.2
Difference	0	-5	0.8	—0.6	—87	—1	+8	0	—10	+1.6	—6.9	—26.1
2 × 10 F_1	7/21	9/21	3.2	7.0	995	98	5	1	10	2.1	89.8	58.2
F_2	7/23	9/15	3.2	6.0	926	38	11	3	72	2.5	86.6	24.0
Difference	+2	-6	0	—1.0	—69	—60	+6	+2	+62	+0.4	—3.2	—34.2
Average F_1	7/19	9/18	3.1	6.5	1,026	42	3	1	35	2.3	85.5	51.7
Average F_2	7/20	9/16	2.7	5.5	949	23	10	3	45	2.7	79.5	25.1
Original	7/23	9/20	3.0	6.5	1,244	48	8	2	49	2.8	81.0	37.5
Average of pure lines[1]	7/23	9/16	1.7	4.2	708	6	6	3	20	2.3	76.0	10.3

[1]Data for pure line parents compiled from Table 14 by including each in the average as often as it occurs in the hybrids.

The F_2 hybrids were compared directly with the original corn, and their yields are here corrected to check plat yields, to be comparable with the yield of the other corn.

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TABLE 17.—*Comparison of first, second, and third generation hybrids of pure lines of Hogue's Yellow Dent corn with the original variety. 1917.*

Description	Date tasseling	Date ripe	Ear height	Stalk height	Suckers per 100 plants	Barren plants per 100	Two-eared stalks per 100 plants	Lodging	Shrinkage of ear corn	Shelling per cent	Yield per acre
(1)	(2)	(3)	*Feet* (4)	*Feet* (5)	(6)	(7)	(8)	*Per cent* (9)	*Per cent* (10)	*Per cent* (11)	*Bushels* (12)
4 × 12 F_1	8/6	10/2	3.2	7.2	9	0	4	7	3.8	85.0	60.6
F_2	8/5	10/1	3.0	5.0	2	0	5	33	6.7	83.5	32.0
F_3	8/2	10/1	2.0	4.7	3	4	12	27	5.3	83.0	22.3
4 × 1 F_1	8/5	9/28	3.2	6.0	12	6	36	13	2.3	81.4	41.6
F_2	8/4	9/29	3.0	5.5	6	1	39	29	8.7	80.8	26.4
F_3	8/1	9/29	2.2	4.5	3	13	18	9	4.4	77.9	20.0
12 × 5 F_1	8/5	10/1	3.5	6.5	2	3	23	10	6.8	81.4	48.5
F_2	8/3	9/28	3.0	5.7	2	1	7	57	6.7	78.8	22.8
F_3	8/3	9/28	2.5	5.2	0	5	1	56	6.6	75.9	19.3
8 × 2 F_1	8/6	10/2	3.5	6.6	3	0	1	16	6.6	88.4	51.9
F_2	8/5	10/3	3.0	6.2	2	2	3	38	8.7	88.3	30.0
F_3	8/4	10/2	2.7	5.2	6	1	5	52	8.9	84.8	27.2
12 × 2 F_1	8/4	10/1	3.4	7.0	5	2	16	22	6.9	86.3	59.4
F_2	8/4	10/2	3.0	5.5	0	4	9	46	7.0	85.5	32.1
F_3	8/3	9/29	2.7	5.2	2	3	4	41	5.4	85.6	32.7
10 × 12 F_1	8/5	10/1	3.7	7.0	11	0	35	10	6.0	78.7	53.6
F_2	8/4	10/1	3.0	5.5	2	1	12	58	3.0	85.6	29.9
F_3	8/3	9/30	2.7	5.0	4	2	2	62	3.1	85.0	28.3
*8 × 10 F_1	8/6	10/1	3.0	6.0	2	7	4	35	12.3	80.7	16.4
F_2	8/7	10/2	2.0	5.0	3	0	11	26	7.4	84.1	18.0
F_3	8/7	10/2	2.2	4.7	0	2	10	44	10.0	83.3	21.2
2 × 10 F_1	8/6	10/3	3.2	7.0	5	3	13	20	4.7	88.4	45.2
F_2	8/4	10/2	3.2	6.5	5	2	11	37	2.1	89.1	32.7
F_3	8/4	10/1	2.7	5.5	1	1	3	37	5.1	88.6	29.3
Average F_1	8/5	10/1	3.4	6.8	7	2	18	18	5.3	84.2	51.5
Average F_2	8/4	10/1	3.0	5.7	3	2	12	43	6.1	84.5	29.4
Average F_3	8/3	9/30	2.5	5.0	3	4	6	41	5.5	83.0	25.6
Original	8/5	10/1	3.5	6.7	9	6	3	22	7.9	83.2	46.0

*The 8 × 10 was omitted from the averages because of its uncharacteristic hybrid behavior.

The three generations of corn were each compared directly with the original corn, which was used in check plats. In this table the second and third generations have been corrected according to check plats in order to make them comparable with the F_1 generation.

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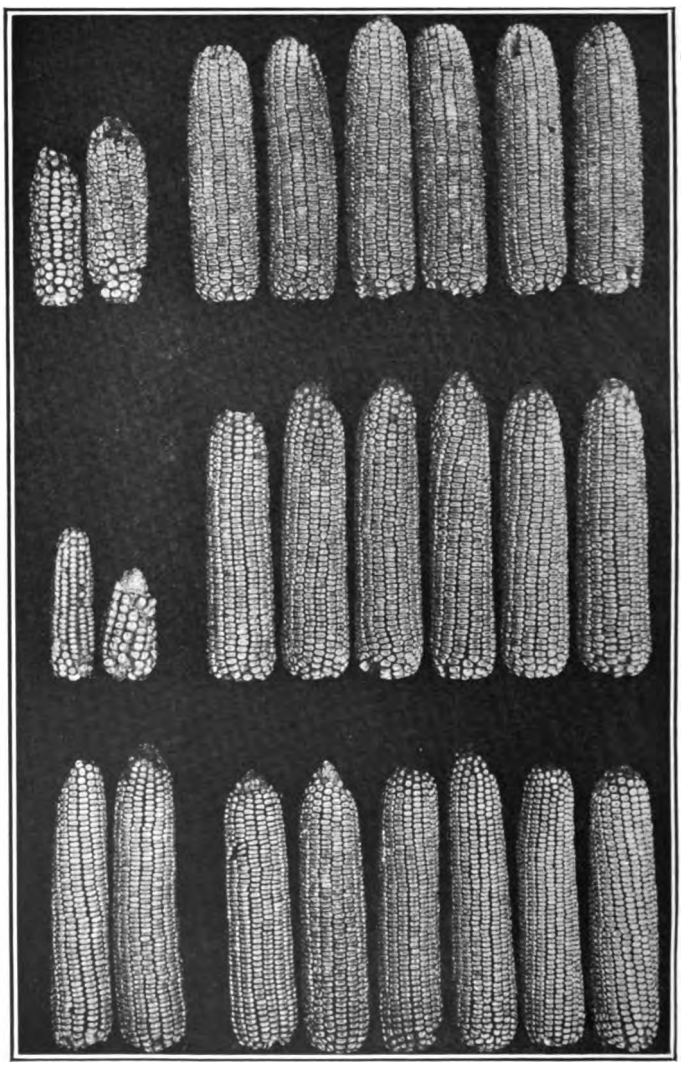

Fig. 16.—Representative ears showing effects of prolonged inbreeding followed by crossing of the homozygous pure lines. Lower row: Original commercial seed at left and progeny at right. Upper two rows: Inbred parents at left and first generation hybrid progeny at right.

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TABLE 18.—*Summary of first and second generation hybrids of pure lines of Hogue's Yellow Dent corn. 1916-1917.*

Pure lines crossed	Yield per acre (bushels)					
	First generation		Second generation		2-year average	
	1916	1917	1916	1917	F_1	F_2
(1)	(2)	(3)	(4)	(5)	(6)	(7)
4 × 12	38.8	60.6	21.6	32.0	49.7	26.8
4 × 1	53.2	41.6	31.4	26.4	47.4	28.9
12 × 5	44.6	48.5	15.9	22.8	46.5	19.3
8 × 2	66.2	51.9	38.3	30.0	59.0	34.1
12 × 2	58.0	59.4	28.0	32.1	58.7	30.0
10 × 12	51.5	53.6	24.1	29.9	52.5	27.0
2 × 10	58.2	45.2	24.0	32.7	51.7	28.3
Average	52.9	51.5	26.2	29.4	52.2	27.8
Original	37.5	46.0	37.5	46.0	41.7	41.7

HOGUE'S YELLOW DENT "LEAF AREA" PURE LINES AND HYBRIDS

ORIGINAL STOCK

The origin of these selections dates back to 1905. In that year a large number of ordinary wind fertilized Hogue's Yellow Dent corn plants were measured individually for leaf area and for dry matter. The ratio of leaf area (in square inches) to dry matter (in grams) was calculated as a basis for type selection. The ears from two plants having a low ratio of leaf area per gram dry matter served as the foundation for "low leaf area" selections, while the ears from two plants having a high ratio of leaf area per gram dry matter formed the foundation for the "high leaf area" selection. The four ears were planted individually in ear-to-row plats in 1906 and a number of individual plants of their respective types selected from the progeny for planting ear-to-row plats in 1907. During 1907, 1908, and 1909, the "low leaf area" selections were planted in one isolated group of ear-to-row plats while the "high leaf area" selections were grown in another isolated group. This permitted free pollination between the strains selected for their respective types but avoided cross-pollination between the high and the low leaf area selections. In 1909, after three years' continuous selection respectively for high and low ratio of leaf area to dry matter,

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TABLE 19.—*Description of the "high leaf area" and the "low leaf area" selections in 1909 from which the pure line "leaf area" strains recorded in Table 20 were derived by selfing during five successive years.*

Pure lines derived from 1909 stock No.	Foundation stock number, 1909	Description of foundation "leaf area" selections, 1909							
		Date ripe	Height of stalk	Height of ear	Weight of stover	Weight of ear	Total weight	Leaf area per plant	Leaf area per gram dry weight
(1)	(2)	(3)	*Inches* (4)	*Inches* (5)	*Grams* (6)	*Grams* (7)	*Grams* (8)	*Sq. in.* (9)	*Sq. in.* (10)
				"HIGH LEAF AREA" SELECTIONS					
721, 743	94	9/20	113	54	268.9	264.9	533.8	1,541	2.89
722	921	9/21	112	55	216.9	255.3	472.2	1,471	3.12
725	93	9/21	109	50	221.3	265.5	486.8	1,450	2.98
726	92	9/20	111	52	246.9	271.6	518.5	1,561	3.01
728	91	9/20	112	53	253.5	257.1	510.6	1,448	2.83
741	98	9/20	115	47	245.6	313.0	558.6	1,407	2.52
746	97	9/19	114	52	254.9	312.9	568.0	1,561	2.75
Average		9/20	112	52	244.0	277.2	521.2	1,491	2.87
				"LOW LEAF AREA" SELECTIONS					
730	925	9/17	110	40	206.5	247.7	454.2	1,049	2.31
731, 752, 753	924	9/16	112	46	232.6	276.8	509.4	1,207	2.37
732, 733, 734, 748	940	9/14	110	44	206.2	293.5	499.7	1,178	2.36
751, 735	938	9/13	106	43	213.6	278.1	491.7	1,147	2.38
736	937	9/14	114	44	218.4	285.2	503.6	1,174	2.33
737	933	9/14	108	45	246.1	286.8	532.9	1,240	2.37
738, 739	936	9/13	110	48	194.9	255.6	450.5	1,154	2.56
754	923	9/16	112	53	234.7	257.9	492.6	1,197	2.43
755, 756	942	9/15	106	44	247.2	275.8	523.0	1,073	2.05
Average		9/15	110	45	222.2	273.0	495.2	1,157	2.35

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these selections tended strongly to come true to type, tho there was still considerable variation between the individual plants. The comparative growth characteristics of these different selections before inbreeding is shown for 1909 in Table 19.

Comparing the average of the low leaf area selections with the average of the high leaf area selections, the former had 82 per cent as much leaf area per gram dry matter, 77 per cent as much actual leaf area, 95 per cent as much total dry matter, 99 per cent as great ear weight, grew two inches shorter, and matured five days earlier. These comparisons were all based on individual measurements of ten representative plants for each strain. In addition to the above differences, a very distinct difference in ear type had unconsciously been developed for the two general groups. The low leaf area selection had a more slender ear, with shallower and flintier kernel, than the original variety. The high leaf area selections, on the other hand, were characterized by a somewhat larger ear circumference and a deeper and rougher kernel.

INBRED STRAINS

During the six years 1909-1915 (omitting 1913), these 8 high and 17 low leaf area strains were subjected to continuous self-fertilization. The comparative growth at the end of this period of reduction to elemental strains is shown in Table 20, which gives the averages for the two years 1915-1916. Comparing the average of the low leaf area pure lines with the average of the high leaf area pure lines, the former had 84 per cent as much leaf area per gram dry matter, 76 per cent as much actual leaf area, 94 per cent as much total dry matter, 125 per cent as great ear weight, grew 2 inches taller, and matured 5 days earlier.

In the more important characteristics, practically the same relationships obtained between the two groups of pure lines as existed before self-fertilization. However, a great reduction in plant size and productivity had resulted from the continuous self-fertilization.

HYBRIDS BETWEEN LEAF AREA PURE LINES

During 1915 and 1916 a comparative yield test was made of (1) 18 F_1 hybrids between low leaf area pure lines, (2) 4 F_1 hybrids between high leaf area pure lines, (3) 7 F_1 hybrids between high and low leaf area pure lines, and (4) original Hogue's Yellow Dent corn. The results are given in Table No. 21.

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ABLE 20.—*Plant characters for leaf area inbreds. A*
two years, 1915-1916.

Average line No.	1909 strain number	1905 family number	Date tassel-ing	Date ripe	Height ear	Height stalk	Dry weight stover	Dry weight ears	Total dry weight plant
					Feet	*Feet*	*Grams*	*Grams*	*Grams*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
					HIGH LEAF AREA INBRED STRAINS				
7102	5961	36	8/1	9/25	2.4	5.2	124.9	29.7	154.6
7103	5962	36	8/5	9/27	2.9	6.0	116.0	41.3	157.3
7105	5963	36	8/8	9/28	2.4	5.3	107.2	44.5	151.7
7106	5964	36	8/8	9/28	2.4	5.0	138.1	41.6	179.7
7108	5965	36	8/7	9/28	2.3	4.3	132.3	25.2	157.5
7111	5966	3113	8/8	9/28	2.5	5.4	163.6	38.0	201.6
7112	5967	36	8/7	9/28	2.4	5.2	112.7	47.2	159.9
7116	5971	3113	8/7	9/28	2.9	4.4	138.5	66.6	205.1
Average			8/7	9/28	2.4	5.1	129.2	41.8	170.9
					LOW LEAF AREA INBRED STRAINS				
7126	5925	3110	7/30	9/24	2.0	5.3	85.8	54.2	140.0
7131	5931	3110	7/30	9/24	2.7	6.1	69.5	84.7	154.2
7133	5933	3110	8/2	9/26	2.5	5.4	102.8	30.8	133.6
7135	5935	3110	7/30	9/23	2.5	5.0	97.8	18.4	116.2
7136	5936	3110	8/1	9/26	2.7	5.6	90.5	35.4	125.9
7137	5937	3110	8/1	9/24	2.7	5.7	109.5	80.6	190.1
7138	5938	3110	7/28	9/21	2.3	5.3	109.3	54.3	163.6
7141	5941	3110	7/30	9/21	2.1	6.5	102.5	64.0	166.5
7142	5942	3110	7/28	9/21	2.0	4.2	105.0	9.3	114.3
7144	5944	3110	7/28	9/21	2.1	4.8	100.3	34.2	134.5
7145	5945	3110	7/30	9/21	2.6	5.7	140.3	42.4	186.7
7146	5946	3110	7/30	9/26	2.6	5.9	105.6	55.7	161.3
7147	5947	3110	7/30	9/29	2.7	6.3	147.4	56.2	203.6
7148	5948	3110	7/30	9/21	2.5	4.5	94.6	59.8	154.4
7150	5950	3110	7/31	9/26	2.9	4.5	120.4	109.3	229.7
7151	5951	3110	7/30	9/26	2.6	5.0	137.4	77.0	214.4
7152	5952	3110	7/30	9/28	2.8	6.0	96.3	29.4	125.7
Average			7/30	9/26	2.6	5.3	108.8	62.1	169.9
Grand			7/30	9/26	2.5	7.9	287.1	102.4	549.1

Comparing the averages of the low leaf ar
inbreds with the average high leaf area pure line
grown had 81 per cent as much leaf area per gram
81 per cent as much actual leaf area, 99 per cent a
dry matter, 101 per cent as great ear weight, 85
ripen earlier, and matured 3 days earlier. The aver

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omparison of first generation hybrids of pure lines of Hogue's Yellow Dent high leaf low leaf area selections with the original variety. Two-year average, 1915 and 1916.

Date ripe	Ear height	Stalk height	Suckers per 100 plants	Barren plants per 100	2-eared stalks per 100 plants	Lodging	Weight stover per plant	Weight ear per plant	Total plant weight	Leaf area per plant	Leaf area per gram dry matter	Shrinkage of ear corn	Shelling per cent	Yield per acre
(3)	*Feet* (4)	*Feet* (5)	(6)	(7)	(8)	*Per cent* (9)	*Grams* (10)	*Grams* (11)	*Grams* (12)	*Sq. in.* (13)	*Sq. in.* (14)	*Per cent* (15)	*Per cent* (16)	*Bu.* (17)
HYBRIDS OF LOW LEAF AREA PURE LINES														
9/25	4.0	8.0	48	4	25	49	245.0	360.0	605.0	1,059	1.75	4.0	85.1	57.9
9/24	3.7	7.8	51	1	25	35	171.3	296.5	467.8	852	1.82	3.2	83.4	54.9
9/26	2.6	6.4	3	5	48	5	173.7	168.3	342.0	950	2.78	6.4	83.7	31.8
9/25	3.4	7.8	34	2	29	3	237.9	350.7	588.6	1,088	1.85	4.9	84.1	66.2
9/25	3.2	7.5	62	1	52	21	196.9	378.6	575.5	969	1.68	6.7	84.0	72.1
9/25	3.8	8.2	3	1	41	29	220.2	408.6	628.8	1,210	1.92	6.1	84.0	65.8
9/25	3.7	7.9	4	3	9	43	209.0	242.0	451.0	1,051	2.34	7.6	84.5	44.8
9/26	3.5	7.8	8	1	38	21	291.4	325.6	617.0	1,289	2.09	6.4	82.6	63.2
9/25	3.5	8.2	56	5	11	5	244.8	327.2	572.0	987	1.72	4.2	79.0	51.9
9/25	3.4	8.1	80	4	34	48	187.3	320.0	507.3	968	1.91	5.6	82.7	65.5
9/25	4.0	8.3	49	2	45	21	213.2	282.9	496.1	1,130	2.28	7.2	85.6	71.8
9/26	4.1	8.2	16	1	33	21	259.7	375.0	634.7	1,367	2.15	6.5	83.6	65.4
9/24	3.9	8.0	17	3	40	41	211.2	290.0	501.2	1,138	2.27	8.0	86.9	70.4
9/24	3.2	6.7	42	5	30	59	178.4	298.3	476.7	928	1.95	7.6	82.7	52.4
9/25	3.8	7.6	10	0	43	47	191.0	284.9	475.9	1,118	2.35	8.2	85.2	64.7
9/25	3.5	8.1	61	0	30	30	204.6	324.4	529.0	943	1.78	6.3	84 0	72.8
9/24	3.9	8.1	46	2	42	49	239.0	378.5	617.5	1,151	1.86	6.6	84.8	64.5
9/25	3.7	8.1	17	5	8	33	221.7	342.0	563.7	1,117	1.98	7.2	86.1	74.1
9/25	3.6	7.8	34	2.5	32	31	216.4	319.6	536.0	1,073	2.02	6.2	84.0	61.7
HYBRIDS OF HIGH LEAF AREA PURE LINES														
9/23	3.7	7.3	11	2	39	5	247.5	309.0	556.5	1,268	2.28	8.6	78.4	68.9
9/23	3.3	6.6	8	2	24	22	208.8	236.7	445.5	1,240	2.80	6.4	80.1	54.0
9/23	3.5	7.7	22	1	24	47	282.0	348.5	610.5	1,324	2.17	10.8	65.9	40.7
9/23	3.4	7.2	26	2	40	7	246.0	302.0	548.0	1,402	2.56	6.9	81.2	58.8
9/23	3.5	7.2	17	2	32	20	241.1	299.0	540.1	1,311	2.45	8.2	76.4	55.6
HYBRIDS OF LOW LEAF AREA BY HIGH LEAF AREA PURE LINES														
9/26	2.7	7.3	17	2	32	57	241.0	314.8	555.8	986	1.77	9.5	78.7	51.5
9/26	3.4	7.2	20	6	36	31	152.7	294.9	447.6	1,273	2.84	4.3	81.6	55.3
9/25	3.6	7.8	17	1	8	12	287.2	342.0	629.2	1,246	1.98	7.1	82.3	62.3
9/26	3.6	8.0	7	1	49	8	306.2	367.2	673.4	1,520	2.26	6.6	81.6	63.4
9/25	3.8	7.6	8	1	51	32	238.5	296.0	534.5	1,376	2.57	5.0	82.6	66.3
9/26	3.5	7.9	3	1	39	32	304.7	314.7	619.4	1,358	2.19	8.0	82.3	54.9
9/25	3.3	7.4	17	1	14	17	222.7	299.2	521.9	1,219	2.33	4.7	81.3	60.7
9/26	3.4	7.6	13	2	33	27	250.4	318.4	568.8	1,283	2.28	6.4	81.5	59.2
9/25	3.5	7.9	63.7	2	30	50.2	237.1	312.4	549.5	1,256	2.29	8.3	84.1	55.1

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TABLE 20.—*Plant characters for leaf area inbreds. Average for two years, 1915-1916.*

Pure line No.	1909 stock number	1905 family number	Date tasseling	Date ripe	Height ear	Height stalk	Dry weight stover	Dry weight ears	Total dry weight plant	Leaf area per stalk	Leaf area per gram dry matter
					Feet	*Feet*	*Grams*	*Grams*	*Grams*	*Sq. in.*	*Sq. in.*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
HIGH LEAF AREA INBRED STRAINS											
721	94	56	8/1	9/25	2.4	5.2	124.9	29.7	154.6	695	4.49
722	921	56	8/5	9/27	2.9	6.0	116.0	41.3	157.3	1,006	6.40
725	93	56	8/8	9/28	2.4	5.3	107.2	44.5	151.7	682	4.49
726	92	56	8/9	9/28	2.4	5.0	138.1	41.6	179.7	993	5.53
728	91	56	8/7	9/28	2.3	4.3	132.3	25.2	157.5	821	5.21
741	98	5113	8/8	9/28	2.6	5.4	163.6	38.0	201.6	831	4.12
743	94	56	8/7	9/28	2.4	5.2	112.7	47.2	159.9	781	4.88
746	97	5113	8/7	9/28	2.0	4.4	138.5	66.6	205.1	804	3.92
Average			8/7	9/28	2.4	5.1	129.2	41.8	170.9	827	4.88
LOW LEAF AREA INBRED STRAINS											
730	925	5123	7/30	9/24	2.0	5.3	85.8	54.2	140.0	555	3.96
731	924	5128	7/30	9/24	2.7	6.1	69.5	84.7	154.2	724	4.69
732	940	5132	8/2	9/26	2.5	5.4	112.8	20.8	133.6	687	5.14
733	940	5132	7/30	9/23	2.8	5.0	97.8	18.4	116.2	614	5.28
734	940	5132	8/1	9/23	2.7	5.6	90.5	35.4	125.9	698	5.54
735	938	5132	8/1	9/24	2.7	5.7	109.5	80.6	190.1	715	3.76
736	937	5132	7/28	9/21	2.2	5.3	109.3	54.3	163.6	576	3.52
737	933	5132	7/30	9/21	3.1	6.5	132.5	64.0	196.5	692	3.52
738	936	5132	7/28	9/21	3.0	4.2	105.0	9.3	114.3	707	6.18
739	936	5132	7/29	9/21	2.1	4.8	100.3	84.2	184.5	547	4.07
748	940	5132	7/28	9/21	2.9	5.7	144.3	42.4	186.7	658	3.52
751	938	5132	7/30	9/23	2.6	5.0	105.6	55.7	161.3	451	2.80
752	924	5132	7/29	9/23	2.7	6.3	147.4	56.2	203.6	856	4.20
753	924	5132	7/25	9/21	2.5	4.5	94.6	59.8	154.4	556	3.60
754	923	5132	7/31	9/25	1.9	4.5	110.4	109.3	219.7	559	2.54
755	942	5132	7/30	9/24	2.6	5.0	137.4	77.0	214.4	634	2.96
756	942	5132	7/26	9/22	2.6	6.0	96.3	29.4	125.7	511	4.07
Average			7/29	9/23	2.6	5.3	108.8	52.1	160.9	632	4.08
Original			7/28	9/25	3.5	7.9	237.1	312.4	549.5	1,256	2.29

[1]Measurements were not made for the original corn grown directly in connection with these pure lines. Therefore the data for the original corn, obtained under similar conditions in comparison with the hybrids between these pure lines and recorded in Table 21, are given here.

Comparing the averages of the low leaf area pure line hybrids with the average high leaf area pure line hybrids, the former had 82 per cent as much leaf area per gram dry matter, 82 per cent as much actual leaf area, 99 per cent as much total dry matter, 107 per cent as great ear weight, stalk height 6 inches taller, and matured 3 days earlier. The same two rather distinct ear types prevailed for the two groups that were noted

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-Comparison of first generation hybrids of pure lines of Hogue's Yellow Dent high leaf
d low leaf area selections with the original variety. Two-year average, 1915 and 1916.

ate tel- g	Date ripe	Ear height	Stalk height	Suckers per 100 plants	Barren plants per 100	2-eared stalks per 100 plants	Lodging	Weight stover per plant	Weight ear per plant	Total plant weight	Leaf area per plant	Leaf area per gram dry matter	Shrinkage of ear corn	Shelling per cent	Yield per acre
)	(3)	Feet (4)	Feet (5)	(6)	(7)	(8)	Per cent (9)	Grams (10)	Grams (11)	Grams (12)	Sq. in. (13)	Sq. in. (14)	Per cent (15)	Per cent (16)	Bu. (17)
						HYBRIDS OF LOW LEAF AREA PURE LINES									
9	9/25	4.0	8.0	48	4	25	49	245.0	360.0	605.0	1,059	1.75	4.0	85.1	57.9
7	9/24	3.7	7.8	51	1	25	35	171.3	296.5	467.8	852	1.82	3.2	83.4	54.9
	9/26	2.6	6.4	3	5	48	5	173.7	168.3	342.0	950	2.78	6.4	83.7	31.8
6	9/25	3.4	7.8	34	2	29	3	237.9	350.7	588.6	1,088	1.85	4.9	84.1	66.2
7	9/25	3.2	7.5	62	1	52	21	196.9	378.6	575.5	969	1.68	6.7	84.0	72.1
8	9/25	3.8	8.2	3	1	41	29	220.2	408.6	628.8	1,210	1.92	6.1	84.0	65.8
6	9/25	3.7	7.9	4	3	9	43	209.0	242.0	451.0	1,051	2.34	7.6	84.5	44.8
7	9/26	3.5	7.8	8	1	38	21	291.4	325.6	617.0	1,289	2.09	6.4	82.6	63.2
8	9/25	3.5	8.2	56	5	11	5	244.8	327.2	572.0	987	1.72	4.2	79.0	51.9
7	9/25	3.4	8.1	80	4	34	48	187.3	320.0	507.3	968	1.91	5.6	82.7	65.5
8	9/25	4.0	8.3	49	2	45	21	213.2	282.9	496.1	1,130	2.28	7.2	85.6	71.8
9	9/26	4.1	8.2	16	1	33	21	259.7	375.0	634.7	1,367	2.15	6.5	88.6	65.4
4	9/24	3.9	8.0	17	3	40	41	211.2	290.0	501.2	1,138	2.27	8.0	86.9	70.4
5	9/24	3.2	6.7	42	5	30	59	178.4	298.3	476.7	928	1.95	7.6	82.7	52.4
9	9/25	3.8	7.6	10	0	43	47	191.0	284.9	475.9	1,118	2.35	8.2	85.2	64.7
7	9/25	3.5	8.1	61	0	30	30	204.6	324.4	529.0	948	1.78	6.3	84 0	72.8
5	9/24	3.9	8.1	46	2	42	49	239.0	378.5	617.5	1,151	1.86	6.6	84.8	64.5
7	9/25	3.7	8.1	17	5	8	33	221.7	342.0	563.7	1.117	1.98	7.2	86.1	74.1
7	9/25	3.6	7.8	34	2.5	32	31	216.4	319.6	536.0	1,075	2.02	6.2	84.0	61.7
						HYBRIDS OF HIGH LEAF AREA PURE LINES									
1	9/28	3.7	7.3	11	2	39	5	247.5	309.0	556.5	1,268	2.28	8.6	78.4	68.9
0	9/23	3.3	6.6	8	2	24	22	208.8	236.7	445.5	1,240	2.80	6.4	80.1	54.0
1	9/23	3.5	7.7	22	1	24	47	262.0	348.5	610.5	1,324	2.17	10.8	65.9	40.7
1	9/2	3.4	7.2	26	2	40	7	246.0	302.0	548.0	1,402	2.56	6.9	81.2	58.8
1	9/23	3.5	7.2	17	2	32	20	241.1	299.0	540.1	1,311	2.45	8.2	76.4	55.6
						HYBRIDS OF LOW LEAF AREA BY HIGH LEAF AREA PURE LINES									
0	9/26	2.7	7.3	17	2	32	57	241.0	314.8	555.8	986	1.77	9.5	78.7	51.5
9	9/26	3.4	7.2	20	6	36	31	152.7	294.9	447.6	1,273	2.84	4.3	81.6	55.3
7	9/25	3.6	7.8	17	1	8	12	287.2	342.0	629.2	1,246	1.98	7.1	82.3	62.3
0	9/26	3.6	8.0	7	1	49	8	306.2	367.2	673.4	1,520	2.26	6.6	81.6	63.4
8	9/25	3.8	7.6	8	1	51	32	238.5	296.0	534.5	1,376	2.57	5.0	82.6	66.3
0	9/26	3.5	7.9	3	1	39	32	304.7	314.7	619.4	1,358	2.19	8.0	82.3	54.9
6	9/25	3.3	7.4	17	1	14	17	222.7	299.2	521.9	1,219	2.33	4.7	81.3	60.7
9	9/26	3.4	7.6	13	2	33	27	250.4	318.4	568.8	1,283	2.28	6.4	81.5	59.2
8	9/25	3.5	7.9	63.7	2	30	50.2	237.1	312.4	549.5	1,256	2.29	8.3	84.1	55.1

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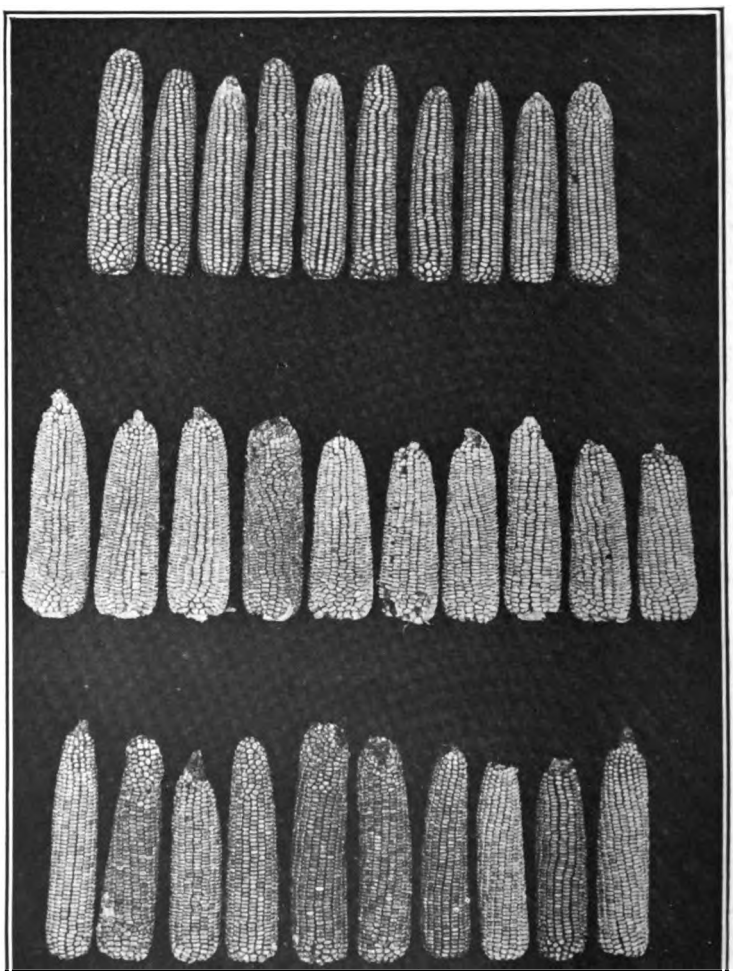

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It is interesting to note that the principal character, viz, ratio of leaf area to dry matter, showed an identical difference for the two groups in all three conditions—before inbreeding, after inbreeding, and after crossing. The plant and ear types, which had been fairly well fixed by ordinary plant selection within a variety, were carried over thru the inbreeding period for five years and retained in the F_1 pure line hybrids.

The F_1 hybrids between low leaf and high leaf area pure lines were intermediate in their ratio of leaf area to dry weight and also in ear type. Considerable variation occurred between different hybrids in yield of grain per acre, but as an average the hybrids were considerably more productive than the original. The yields of the low leaf hybrids, high leaf hybrids, low by high leaf hybrids, and the original averaged respectively 61.7, 55.6, 59.2, and 55.1 bushels. This is a 12 per cent greater yield for the average of the low leaf pure line hybrids compared with the original variety, while the highest yielding individual hybrid yielded 34 per cent more.

RELATION BETWEEN VIGOR OF PURE LINE PARENTS AND PRODUCTIVITY OF FIRST GENERATION HYBRIDS

There has been much speculation regarding the relation between the vigor of the pure lines and of their hybrid progeny. The general concensus of opinion among students of this problem would seem to support the theory that those elemental strains which undergo the least reduction from inbreeding are likely to produce the most productive hybrid offspring when crossed.

The observations at this Station bearing upon this point may be of interest, altho they are hardly of sufficient extent to warrant conclusions. The yields of eight F_1 hybrids and their inbred parents are given for 1916 in Table 22. The average yield of the four hybrids in each of which the lowest yielding parent yielded not to exceed 3.1 bushels per acre was 45.0 bushels. In comparison, the average yield of the four hybrids in none of which the lowest yielding parent produced less than 8.0 bushels was 58.5 bushels per acre.

The average superiority in grain yield of the inbred parents of the second group over those of the first group was 34 per cent. In comparison, the average superiority in grain yield of

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TABLE 22.—*Comparison of first generation hybrids and their pure line parents, Hogue's Yellow Dent corn, (Class IX). 1916.*

Hybrid	Stalk height				Yield, grain per acre			
	Hybrids		Parents		Hybrids		Parents	
	F_1	F_2	Female	Male	F_1	F_2	Female	Male
	Feet	*Feet*	*Feet*	*Feet*	*Bu.*	*Bu.*	*Bu.*	*Bu.*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
4 × 12....	6.0	5.7	3.7	4.6	38.8	21.6	2.3	14.8
4 × 1.....	5.9	5.7	3.7	3.8	53.2	31.4	2.3	14.5
12 × 5.....	6.7	6.2	4.6	4.5	44.6	15.9	14.8	3.1
10 × 5.....	6.3	5.7	4.5	4.5	43.3	17.2	15.4	3.1
Average....	6.2	5.8	4.1	4.3	45.0	21.5	8.7	8.9
8 × 2.....	6.5	4.7	4.4	3.8	66.2	38.3	10.8	8.0
12 × 2.....	6.7	4.7	4.6	3.8	58.0	28.0	14.8	8.0
10 × 12....	6.7	5.7	4.5	4.6	51.5	24.1	15.4	14.8
2 × 10....	7.0	6.0	3.8	4.5	58.2	24.0	8.0	15.4
Average....	6.7	5.3	4.3	4.2	58.5	28.6	12.2	11.5
Original....	6.5	6.5	6.5	6.5	37.5	37.5	37.5	37.5

These data are compiled from Tables 14 and 16.

individual plant and ear weights of their inbred parents. The hybrids are grouped into the five highest, eight intermediate, and five lowest, yielding hybrids. The respective average yields of these three hybrid groups were 72.2, 64.1, and 47.2 bushels per acre, which is equivalent to the relative yields of 100, 89, and 65 per cent. The corresponding relative ear weights of the inbred parents of the three groups were 100, 86, and 65, while the respective relative total plant weights were 100, 97, and 86 per cent.

There appears to be some general correlation between productivity of the pure line parents and that of their hybrid offspring. Exceptions to this general relation occur.

It is doubtful if maximum increased vigor as indicated by plant size is necessarily the vigor character to be striven for. Some of the most productive hybrids which this Station has produced are shorter growing and have a smaller vegetative development than the original corn from which they came.

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TABLE 23.—*Comparison of first generation hybrids and their pure line parents. Hogue's Yellow Dent low leaf area strains. Two-year average, 1915 and 1916.*

Hybrid	Hybrid yield per acre	Moisture free weights of inbred parents					
		Ear weight			Total plant weight		
		Female	Male	Average	Female	Male	Average
(1)	*Bushels* (2)	*Grams* (3)	*Grams* (4)	*Grams* (5)	*Grams* (6)	*Grams* (7)	*Grams* (8)
FIVE HIGHEST YIELDING HYBRIDS							
736 × 754	72.1	54.3	109.3	81.8	163.6	219.7	191.6
735 × 736	71.8	80.6	54.3	67.4	190.1	163.6	176.8
738 × 735	70.4	9.3	80.6	44.9	114.0	190.1	152.0
731 × 739	72.8	84.7	34.2	59.4	154.2	134.5	144.3
754 × 738	74.1	109.3	9.3	59.3	219.7	114.0	166.8
Average	72.2	67.6	57.5	62.6	168.3	164.4	166.3
HYBRIDS INTERMEDIATE IN YIELD							
731 × 736	57.9	84.7	54.3	70.0	154.2	163.6	158.9
751 × 738	66.2	55.7	9.3	32.5	161.3	114.2	137.7
731 × 732	65.8	84.7	20.8	52.7	154.2	133.6	143.9
738 × 734	63.2	9.3	35.4	22.3	114.2	125.9	120.0
737 × 754	65.5	64.0	109.3	66.6	196.5	219.7	208.1
731 × 734	65.4	84.7	35.4	60.0	154.2	125.9	140.0
755 × 754	64.7	77.0	109.3	93.1	214.4	219.7	217.0
738 × 752	64.5	9.3	56.2	32.7	114.2	203.6	158.9
Average	64.1	58.7	53.7	53.7	157.9	163.3	160.6
FIVE LOWEST YIELDING HYBRIDS							
738 × 736	54.9	9.3	54.3	31.8	114.2	163.6	138.9
734 × 732	31.8	35.4	20.8	28.1	125.9	133.6	129.7
748 × 731	44.8	42.4	84.7	63.5	186.7	154.2	170.4
756 × 730	51.9	29.4	54.2	41.8	125.7	140.0	132.8
733 × 753	52.4	18.4	59.8	39.1	116.2	154.4	135.3
Average	47.2	27.0	54.8	40.9	133.7	149.2	141.4

These data are compiled from Tables 20 and 21.

RATE OF GROWTH OF FIRST GENERATION HYBRIDS BETWEEN PURE LINES

The mature kernels of inbred corn (pure lines) commonly weigh less than those of the original heterozygous corn from which they are derived. Cross-fertilized kernels borne on these pure line plants weigh on an average only about ten per cent heavier than selfed kernels. It has been suggested that first generation hybrids of pure lines are at a disad-

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TABLE 24.—*Rate of growth of standard Hogue's Yellow Dent corn, pure line strains, and first generation hybrids between pure lines. 1921.*

Description	Age of plant[1]	Total plant height	Stem height	Length of tassel[2]	No. of leaves exposed	Leaf area per plant	Green plant weight	Length of largest ear
	Days	*Inches*	*Inches*	*Inches*		*Sq. in.*	*Grams*	*Inches*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
DEVELOPMENT BY JUNE 16								
Pure lines..	14	5	.....	.....	6	28	5	.....
Hybrids F_1.	14	9	.....	.....	7	83	15	.....
Original....	14	9	.....	.....	7	85	16	.....
DEVELOPMENT BY JUNE 23								
Pure lines..	21	11	1.3	0.0	8	89	27	.....
Hybrids F_1.	21	18	2.8	0.1	9	212	82	.....
Original....	21	18	2.5	0.0	9	216	90	.....
DEVELOPMENT BY JUNE 30								
Pure lines..	28	17	4.8	0.36	10	259	121	.....
Hybrids F_1.	28	27	10.4	0.36	13	517	290	.....
Original....	28	28	8.0	0.48	12	500	259	.....
DEVELOPMENT BY JULY 7								
Pure lines..	35	25	11.0	1.4	13	436	265	0.06
Hybrids F_1.	35	39	21.2	4.5	15	751	524	0.13
Original....	35	42	22.7	7.0	14	739	505	0.14
DEVELOPMENT BY JULY 14								
Pure lines..	42	37	21.1	7.8	14	657	513	0.21
Hybrids F_1.	42	53	42.0	16.2	15	1,224	1,034	0.84
Original....	42	50	44.0	17.0	15	1,235	1,059	0.93
DEVELOPMENT BY JULY 21								
Pure lines..	49	58	40.0	16.0	14	705	655	1.3
Hybrids F_1.	49	82	66.0	23.0	15	1,200	1,191	4.2
Original....	49	84	71.0	25.0	15	1,245	1,300	4.6
FULL GROWN CORN AUGUST 9								
Pure lines..	68	79	79	18	14	731	.....	4.2
Hybrids F_1.	68	99	99	24	15	1,204	.....	8.6
Original....	68	100	100	27	15	1,260	.....	8.7

[1]Age of plant begins with day the corn came up.

[2]The tassel includes the stem between the last node and the first tassel branch.

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vantage in their early growth because of the reduced kernel size upon which the seedling plant draws for its early nourishment. To overcome this, the substitution of double crossed seed has been suggested in which two unrelated F_1 hybrids are crossed. The hereditary constitution of the resultant kernel is as complex as for the F_1 hybrid and yet the kernels are normal in size. The data in Table 24 record the rate of growth and general early development in 1921 of standard Hogue's Yellow Dent corn having kernels of normal size, with the average results from a number of pure lines which had been inbred for ten years, and with eight vigorous F_1 hybrids between these pure lines. The results suggest that the size of the F_1 hybrid kernel may, in some cases at least, be sufficient to supply ample nourishment for the young plant under normal soil and climatic conditions at time of planting.

DEGREES OF INBREEDING

There are various degrees of kinship between the ovules of the ear and the pollen grains which fertilize them. The past discussion has indicated that a large number of distinct elemental strains with independently inherited Mendelian characters are the basis for an ordinary corn variety, and that broad fertilization to avoid the pairing of identical Mendelian factors is desirable. Investigation has been made to determine the effect of intermediate degrees of close breeding. Two separate experiments have been conducted, one beginning in 1909 with Hogue's Yellow Dent corn and one in 1912 with Nebraska White Prize. Beginning with ear-to-row strains, the following degrees of relationship between source of ovule and pollen have been studied:

1. *Self-fertilization*, in which the seed has been continued each year with a single ear of corn, fertilized by pollen from the same plant.

2. *Close breeding* within an ear-to-row strain, in which the seed has been continued each year with a single ear of corn, fertilized with pollen from a single sister plant of the same strain.

3[a]. *Narrow breeding* within an ear-to-row strain, in which the seed has been continued each year with a single ear of corn, fertilized with composite pollen from 15 sister plants of the same strain.

3[b]. *Narrow breeding* within an ear-to-row strain, in which the seed has been continued each year with ears in composite from 15 sister plants, all fertilized with pollen from a single sister plant of the same strain. Class 3[a] and 3[b] represent the

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same degree, but are the reciprocal of each other. Class 3^a has probably actually had somewhat broader breeding than 3^b, because the full number of ears for continuing 3^b has not always materialized, thereby lowering the relative number of plants represented in the continuation of the strain.

4. *Broad breeding* within an ear-to-row strain, in which the seed is continued each year with a composite of ears from 15 plants, fertilized with composite pollen from 15 sister plants of the same strain.

5. *Crossbreeding* between ear-to-row strains, in which several strains are planted in alternating rows and cross-fertilized by detasseling part of them, seed being selected from the detasseled rows.

6. *Ordinary wind fertilization* within a commercial variety, in which the seed is continued each year with a composite sample of a large number of well-developed ears.

7. *Crossing of varieties*, in which two commercial varieties are planted each year in alternating plats, one of which is detasseled to furnish the hybrid seed.

DEGREES OF INBREEDING, HOGUE'S YELLOW DENT CORN

Five of these degrees of inbreeding, which have just been described, viz, No. 1, 3^a, 4, 5, and 6, have been continuously carried on with Hogue's Yellow Dent corn since 1909. Classes 1 and 3^a were begun in 1909 with each of three ear-to-row strains, selected from each of four high yielding strains, having their origin in an ear-to-row test begun in 1906. The original strains are the same as those described on page 48 as the foundation stock of Hogue's Yellow Dent pure lines. Classes 4 and 5 originated in 1909 from the four highest yielding individual ear-to-row strains selected in 1903. Class 6 merely represents the original wind fertilized variety, seed of which was obtained each year prior to 1910 from R. Hogue, living at a distance of 30 miles from the Station. Since 1910 it has been continued annually in large seed plats at the Nebraska Experiment Station.

The yields have been determined for the various strains of any one degree in composite, rather than individually. Seven years' results are given in Table 25. The five degrees of inbreeding—1, 3^a, 4, 5, and 6—yielded respectively 16.8, 42.2, 49.2, 54.0, and 53.1 bushels per acre. Every degree narrower than that of crossing between ear-to-row strains resulted in a reduction of yield. The more nearly the fertilization approached self-fertilization, the greater the reduction.

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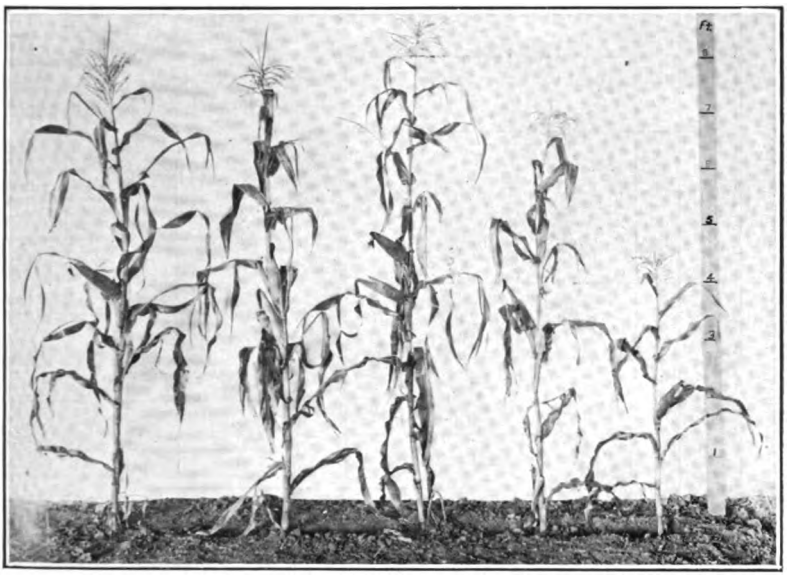

Class No. 6 5 4 3a 1

FIG. 18.—Degrees of inbreeding with Hogue's Yellow Dent corn in 1915. From right to left: (1) Inbreeding; (3a) narrow breeding; (4) broad breeding; (5) natural crossing; (6) original wind fertilized Hogue's Yellow Dent. See Table 25 for seven years' results for these different degrees.

DEGREES OF INBREEDING, NEBRASKA WHITE PRIZE CORN

All the different degrees of inbreeding were carried out with Nebraska White Prize corn. This is a standard full-season, eastern Nebraska variety. The eight highest yielding ear-to-row strains as determined in a two-year (1911-1912) ear-to-row test with 200 ears were subjected to each of the degrees of inbreeding thruout this period. In the comparative yield test for the various degrees, the eight strains of each were grown in composite. The specialized breeding began in each case in 1912. Examination of the five years' results given in Table 26 discloses that the closer the breeding the lower the yield. It would appear that in the production of seed corn any practice should be avoided which might result in any degree of close breeding.

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-*Narrow versus broad fertilization in corn. Hogue's Yellow Dent. Seven years, 1911-1917.*

Description	Yield per acre							
	1911	1912	1913	1914	1915	1916	1917	Av.
(1)	*Bu.* (2)	*Bu.* (3)	*Bu.* (4)	*Bu.* (5)	*Bu.* (6)	*Bu.* (7)	*Bu.* (8)	*Bu.* (9)
eeding (single ear self-fertilized)	19.8	17.2	1.1	14.4	27.0	19.8	18.5	16.8
ow breeding (single ear fertilized with iposite pollen from sister plants)	38.8	44.9	6.2	47.7	61.7	57.2	38.6	42.2
d breeding (composite ears fertilized with iposite pollen from sister plants)	40.9	54.3	8.0	58.3	77.3	60.0	45.8	49.2
ral crossing (between ear-to-row strains)	40.8	53.3	7.8	65.0	84.1	69.4	57.3	53.9
nal wind fertilized corn	41.8	49.6	8.5	63.1	79.5	71.7	57.4	53.1
Number of replications	4	4	4	4	7	4	4	

SUMMARY OF PLANT CHARACTERISTICS. AVERAGE FOR FOUR YEARS, 1914-1917

Description	Stalk height	Ear height	Date tasseling	Date ripe	Leaf area per	Lodging	2-eared stalks per 100	Barren plants per	Suckers per 100	Shrinkage of ear	Shelling per cent

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—*Narrow versus broad fertilization in corn. Nebraska White Prize. Five years, 1915 to 1917 and 1920 to 1921.*

Degree of inbreeding—seed continued by:	Yield of grain per acre					
	1915	1916	1917	1920	1921	Average
(2)	*Bu.* (3)	*Bu.* (4)	*Bu.* (5)	*Bu.* (6)	*Bu.* (7)	*Bu.* (8)
ling (single ear self-fertilized)	33.3	33.0	15.4	11.0	18.6	22.3
reeding (single ear fertilized with pollen from single sister plant)	63.1	49.9	27.6	30.8	42.3	42.7
' breeding (single ear fertilized with composite pollen from sister plants)	58.0	58.2	36.8	38.4	53.0	48.9
' breeding (composite ears fertilized with pollen from single sister plant)	60.0	55.4	30.8	33.4	44.4	44.8
' breeding (average of classes 3*a* and 3*b*)	59.0	56.8	33.8	35.9	48.7	46.8
breeding (composite ears fertilized with composite pollen from sister plants)	56.5	62.1	38.9	38.9	60.8	51.3
l crossing (between ear-to-row strains)	73.7	74.1	47.9	59.1	69.4	64.8
l crossing (between varieties—Nebraska White Prize × Hogue's)	77.9	70.2	50.7	52.8	68.6	64.0
l Nebraska White Prize (wind pollinated)	75.5	73.8	48.2	52.4	68.6	63.7
mber of replications	4	3	3	3	3	

	Summary of plant characteristics. Average for period									
	Stalk height	Ear height	Date tasseling	Date ripe	Lodging	Two-eared stalks per 100 plants	Ears per 100 plants	Suckers per 100 plants	Shrinkage of ear corn	Shelling per cent
	Inches (9)	*Inches* (10)	(11)	(12)	*Per cent* (13)	(14)	(15)	(16)	*Per cent* (17)	*Per cent* (18)
..	87	40	8/5	9/23	27	12	80	7	14.0	76.6
..	94	43	8/5	9/22	26	8	91	11	14.0	80.5
..	97	50	8/4	9/22	25	10	97	12	13.0	80.2
..	97	48	8/4	9/23	25	12	93	16	13.8	81.6
..	97	49	8/4	9/22	25	11	95	14	13.4	80.9
..	98	50	8/4	9/23	27	10	99	16	13.0	81.1
..	101	51	8/3	9/23	28	11	99	16	10.8	82.2
..	100	50	8/1	9/22	31	13	104	20	8.0	83.1
..	101	50	8/3	9/22	28	12	104	18	10.0	82.9

for classes Nos. 1 to 5 is for eight independent strains tested for yield in composite.

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CROSSING VARIETIES

An investigation was carried on with 14 varieties during four years, 1914-1917, to determine what effect the crossing of varieties might have upon the yield of dent corn. A description of the growth habits of the varieties used will be found in Table 27. The varieties used were so selected as to include a wide diversity of growth characteristics. Thirteen hybrids and their parents were tested each year. Their male parent was Hogue's Yellow Dent corn, thruout, while the female parent was different in each case. The F_1 hybrid seed was produced by planting rows of the varieties to serve as the female parents between rows of the Hogue's Yellow Dent. All varieties except Hogue's were kept detasseled, in order to insure their cross-fertilization with Hogue's Yellow Dent. The date of planting the different varieties, for hybridizing, was so adjusted that their flowering period would coincide with that of the Hogue's Yellow Dent.

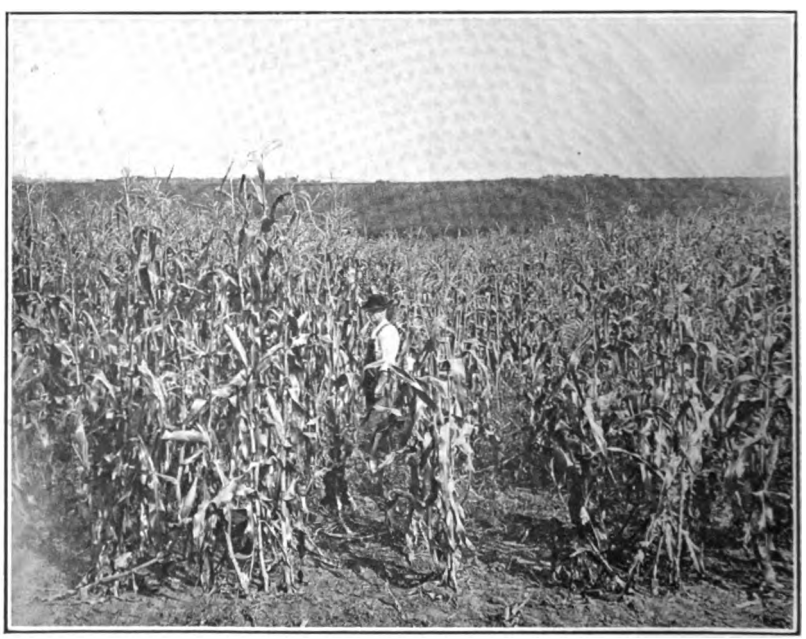

FIG. 19.—Corn to left of man, Hogue's Yellow Dent; to the right, Minnesota No. 13. Note the difference in plant height and vegetative development. To be compared with figure 20. (Table 27.)

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Second and third generation hybrids were produced by artificially close breeding a number of ears in the F_1 and F_2 generations respectively with composite pollen from a number of plants.

RESULTS WITH FIRST GENERATION VARIETY HYBRIDS

Table 28 reports the yields for the four separate years, as well as the average for the period. The difference in yield between the first generation hybrids and their two parents has been calculated. None of the variety crosses showed an increased yield above the better of the two parents. As an average for all the hybrids, the yield was 1.6 bushels lower than the mean for both parents, and four bushels lower than for the best parents. Table 29 summarizes briefly for a number of plant characters the average deviation of all hybrids from the parents individually, as well as from their average. These re-

FIG. 20.—To be compared with figure 19. Corn to left of man, Hogue's Yellow Dent; to the right, first generation hybrid between Hogue's Yellow Dent and Minnesota No. 13. Note the intermediate character of the cross. (Table 27.)

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...--Comparison of first generation corn variety hybrids and their parents. Four year average, 1914-1917.

Description	Date tasseling	Date ripe	Stalk height	Ear height	Suckers per 100 plants	Ears per 100 plants	2 eared stalks per 100 plants	Shrinkage of ear corn	Shelling per cent	Yield per acre	Deviation of hybrid from parent average
(1)	(2)	(3)	In. (4)	In. (5)	(6)	(7)	(8)	Per cent (9)	Per cent (10)	Bu. (11)	Bushels (12)
r Dent ♂	8/1	9/28	[illegible]	48	24	[illegible]4	4	10.19	[illegible]4.0	46.8	
Dent ♀	8/1	9/28	[illegible]5	44	17	[illegible]7	5	7.[illegible]8	[illegible]5.1	44.9	
Dent × Hogue's Yellow Dent F1	8/1	9/28	90	48	22	[illegible]8	5	10.[illegible]8	[illegible]4.7	45.0	0.0
ie ♀	7/29	9/24	[illegible]6	42	18	7[illegible]	4	7.[illegible]8	[illegible]4.9	[illegible]9.[illegible]	
ie × Hogue's Yellow Dent F1	7/30	9/28	[illegible]5	48	22	[illegible]4	4	9.16	[illegible]4.8	46.[illegible]	+1.0
	7/29	9/28	87	48	18	80	5	8.46	[illegible]3.6	46.[illegible]	
gue's Yellow Dent F1	7/31	9/28	90	44	16	[illegible]2	5	[illegible].2[illegible]	[illegible]3.7	43.[illegible]	1.0
	8/4	9/28	[illegible]6	48	18	[illegible]1	5	7.40	[illegible]3.4	46.8	
's Yellow Dent F1	8/3	9/25	[illegible]9	45	19	[illegible]1	4	18.[illegible]9	[illegible]2.[illegible]	40.9	5.5
r ♀	8/5	9/28	[illegible]8	41	12	[illegible]1	2	[illegible].[illegible]4	[illegible]3.1	[illegible]3.7	
r × Hogue's Yellow Dent F1	8/4	9/27	91	48	18	[illegible]4	2	12.[illegible]2	[illegible]2.4	[illegible]0.[illegible]	4.8
White ♀	8/7	9/29	91	41	5	7[illegible]	5	10.[illegible]6	[illegible]0.7	[illegible]5.6	
White × Hogue's Yellow Dent F1	8/5	9/27	92	42	11	[illegible]0	5	[illegible]1.[illegible]8	[illegible]1.[illegible]	[illegible]6.6	5.5
ite ♀	7/30	9/22	[illegible]2	39	2	[illegible]2	1	7.92	[illegible]4.[illegible]	40.[illegible]	
ite × Hogue's Yellow Dent F1	7/31	9/24	[illegible]6	40	6	[illegible]6	2	[illegible].4[illegible]	[illegible]1.6	[illegible]2.[illegible]	+0.2
ne ♀	8/1	9/25	[illegible]3	40	10	[illegible]0	2	9.44	[illegible]2.2	[illegible]0.[illegible]	
ne × Hogue's Yellow Dent F1	8/1	9/26	[illegible]5	42	14	[illegible]1	3	9.49	[illegible]2.6	40.5	1.7
e Prize ♀	8/4	9/27	91	46	9	[illegible]3	3	11.[illegible]1	[illegible]1.2	[illegible]2.[illegible]	
e Prize × Hogue's Yellow Dent F1	8/2	9/26	91	46	18	[illegible]5	4	9.94	[illegible]1.1	40.9	2.9
3 ♀	7/29	9/21	78	40	11	[illegible]1	1	[illegible].[illegible]5	[illegible]2.7	[illegible]1.0	
3 × Hogue's Yellow Dent F1	7/30	9/21	[illegible]1	41	16	[illegible]2	2	10.[illegible]5	[illegible]3.5	42.9	1.2
	7/28	9/21	78	41	5	[illegible]6	3	4.96	[illegible]3.9	[illegible]7.1	
logue's Yellow Dent F1	7/30	9/22	[illegible]1	42	14	[illegible]5	3	7.47	[illegible]4.1	41.2	0.0
rth ♀	7/26	9/14	78	[illegible]8	14	90	[illegible]	5.08	[illegible]2.0	40.1	
rth × Hogue's Yellow Dent F1	7/30	9/23	[illegible]3	42	15	[illegible]5	4	7.[illegible]3	[illegible]5.[illegible]	[illegible]8.6	-4.0
13 ♀	7/22	9/10	68	[illegible]5	4	[illegible]6	2	[illegible].98	[illegible]1.9	[illegible]5.7	
13 × Hogue's Yellow Dent F1	7/28	9/17	79	[illegible]9	9	[illegible]2	2	6.09	[illegible]2.7	42.8	+1.9

were in duplicate each year except Hogue's Yellow Dent, which was replicated fourteen times among the other plats.
parent. ♀ Female parent.

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Yields of first generation corn variety hybrids and their parents during four years, 1914-1917.

Description	Annual yield per acre				Average for the four years	Average yield per acre for four years				Average deviation of hybrid from		
	1914	1915	1916	1917		Male parent	Female parent	Av. both parents	F_1 hybrid	Male parent	Female parent	Av. both parents
(1)	*Bu.* (2)	*Bu.* (3)	*Bu.* (4)	*Bu.* (5)	*Bu.* (6)	*Bu.* (7)	*Bu.* (8)	*Bu.* (9)	*Bu.* (10)	*Bu.* (11)	*Bu.* (12)	*Bu.* (13)
ıt ♂	56.4	42.0	51.6	30.7	45.2							
♀	51.8	53.2	44.4	30.3	44.9							
× Hogue's Yellow Dent F_1	60.7	47.1	41.6	30.5	45.0	45.2	44.9	45.0	45.0	—0.2	+0.1	0.0
	44.9	46.8	42.4	22.4	39.1							
Hogue's Yellow Dent F_1	54.3	49.1	41.9	27.1	43.1	45.2	39.1	42.1	43.1	—2.1	+4.0	+1.0
	55.4	48.5	43.6	25.1	43.1							
Yellow Dent F_1	49.4	48.7	39.7	30.6	42.1	45.2	43.1	44.1	42.1	—3.1	—1.0	—2.0
	54.3	48.0	43.5	27.3	43.3							
ellow Dent F_1	53.4	38.4	44.3	27.6	40.9	45.2	43.3	44.2	40.9	—4.3	—2.4	—3.3
	52.9	43.3	48.2	26.5	42.7							
logue's Yellow Dent F_1	54.7	31.1	44.6	26.0	39.1	45.2	42.7	43.9	39.1	—6.1	—3.6	—4.8
:e ♀	42.4	26.0	51.0	23.0	35.6							
:e × Hogue's Yellow Dent F_1	39.5	35.5	43.0	28.5	36.6	45.2	35.6	40.4	36.6	—8.6	+1.0	—3.8
	50.7	43.4	40.8	25.5	40.1							
(Hogue's Yellow Dent F_1	54.3	43.2	43.5	30.4	42.8	45.2	40.1	42.6	42.8	—2.4	+2.7	+0.2
	45.4	42.3	41.6	27.8	39.3							
Hogue's Yellow Dent F_1	45.9	47.6	39.8	28.8	40.5	45.2	39.3	42.2	40.5	—4.7	+1.2	—1.7
ze ♀	59.2	35.6	51.9	23.4	42.5							
ze × Hogue's Yellow Dent F_1	51.3	38.0	48.3	25.9	41.9	45.2	42.5	43.8	40.9	—4.3	—1.6	—2.9
	53.1	44.5	46.2	28.2	43.0							
Hogue's Yellow Dent F_1	52.7	45.9	46.9	26.0	42.9	45.2	43.0	44.1	42.9	—2.3	—0.1	—1.2
	49.6	42.2	36.3	20.2	37.1							
:'s Yellow Dent F_1	53.1	40.2	47.2	24.2	41.2	45.2	37.1	41.1	41.2	—4.0	+4.1	0.0
♀	45.9	48.7	44.8	20.9	40.1							
× Hogue's Yellow Dent F_1	41.5	44.8	45.9	22.3	38.6	45.2	40.1	42.6	38.6	—6.6	—1.5	—4.0
	49.2	48.9	32.6	12.0	35.7							
(Hogue's Yellow Dent F_1	52.4	51.8	46.6	18.6	42.3	45.2	35.7	40.4	42.3	—2.9	+6.6	+1.9
						45.2	40.5	42.8	41.2	—4.0	+0.7	—1.6

ɪre in duplicate each year except that there were fourteen plats of Hogue's Yellow Dent.
nt. ♀ Female Parent.

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...—*Comparison of first generation corn variety hybrids and their parents. Four-year average, 1914-1917.*

Description	Date tassel-ing	Date ripe	Stalk height	Ear height	Suckers per 100 plants	Ears per 100 plants	2-eared stalks per 100 plants	Shrink-age of ear corn	Shelling per cent	Yield per acre	Deviation of hybrid from parent average
(1)	(2)	(3)	*In.* (4)	*In.* (5)	(6)	(7)	(8)	*Per cent* (9)	*Per cent* (10)	*Bu.* (11)	*Bushels* (12)
...w Dent ♂	8/1	9/23	88	43	24	84	4	10.19	84.0	45.2	
... Dent ♀	8/1	9/23	85	44	17	87	5	7.63	85.1	44.9	
... Dent × Hogue's Yellow Dent F_1	8/1	9/23	90	43	22	88	5	10.68	84.7	45.0	0.0
...ine ♀	7/29	9/24	86	42	13	78	4	7.58	84.9	39.1	
...ine × Hogue's Yellow Dent F_1	7/30	9/23	88	43	22	84	4	9.16	84.3	43.1	+1.0
...	7/29	9/23	87	43	13	80	3	8.46	82.8	43.1	
...ogue's Yellow Dent F_1	7/31	9/23	90	44	16	82	3	8.23	83.7	42.1	—2.0
...	8/4	9/28	86	43	13	81	3	7.40	82.4	43.3	
...ue's Yellow Dent F_1	8/3	9/25	89	45	19	81	4	13.39	82.8	40.9	—3.3
...er ♀	8/5	9/28	88	41	12	81	2	8.34	82.1	42.7	
...er × Hogue's Yellow Dent F_1	8/4	9/27	91	43	18	84	2	12.32	82.4	39.1	—4.8
... White ♀	8/7	9/29	91	41	5	78	3	19.26	80.7	35.6	
... White × Hogue's Yellow Dent F_1	8/5	9/27	92	42	11	80	3	13.18	81.8	36.6	—3.8
...hite ♀	7/30	9/22	82	39	2	82	1	7.92	84.3	40.1	
...hite × Hogue's Yellow Dent F_1	7/31	9/24	86	40	6	86	2	8.43	83.6	42.8	+0.2
...ine ♀	8/1	9/25	83	40	10	80	2	9.44	82.2	39.3	
...line × Hogue's Yellow Dent F_1	8/1	9/26	88	42	14	81	3	9.49	82.6	40.5	—1.7
...ite Prize ♀	8/4	9/27	91	46	9	83	3	11.81	83.2	42.5	
...ite Prize × Hogue's Yellow Dent F_1	8/2	9/26	91	46	13	83	4	9.94	83.1	40.9	—2.9
... 3 ♀	7/29	9/21	78	40	11	81	1	8.85	82.7	43.0	
... 3 × Hogue's Yellow Dent F_1	7/30	9/21	81	41	16	82	2	10.35	83.5	42.9	—1.2
...	7/28	9/21	78	41	5	86	3	4.96	83.9	37.1	
...Hogue's Yellow Dent F_1	7/30	9/22	81	42	14	85	3	7.47	84.1	41.2	0.0
...Jorth ♀	7/26	9/14	78	38	14	90	3	5.08	82.0	40.1	
...Jorth × Hogue's Yellow Dent F_1	7/30	9/23	83	42	15	85	4	7.83	85.8	38.6	—4.0
... 13 ♀	7/22	9/10	68	35	4	86	2	3.98	81.9	35.7	
... 13 × Hogue's Yellow Dent F_1	7/28	9/17	79	39	9	82	2	6.09	82.7	42.8	+1.9

... were in duplicate each year except Hogue's Yellow Dent, which was replicated fourteen times among the other plats.
... parent. ♀ Female parent.

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of first generation corn variety hybrids and their parents during four years, 1914-1917.

ion	Annual yield per acre				Average for the four years	Average yield per acre for four years				Average deviation of hybrid from		
	1914	1915	1916	1917		Male parent	Female parent	Av. both parents	F_1 hybrid	Male parent	Female parent	Av. both parents
	Bu. (2)	Bu. (3)	Bu. (4)	Bu. (5)	Bu. (6)	Bu. (7)	Bu. (8)	Bu. (9)	Bu. (10)	Bu. (11)	Bu. (12)	Bu. (13)
.....	56.4	42.0	51.6	30.7	45.2							
.....	51.8	53.2	44.4	30.3	44.9							
's Yellow Dent F_1....	60.7	47.1	41.6	30.5	45.0	45.2	44.9	45.0	45.0	—0.2	+0.1	0.0
.....	44.9	46.8	42.4	22.4	39.1							
Yellow Dent F_1.....	54.3	49.1	41.9	27.1	43.1	45.2	39.1	42.1	43.1	—2.1	+4.0	+1.0
.....	55.4	48.5	43.6	25.1	43.1							
Dent F_1.....	49.4	48.7	39.7	30.6	42.1	45.2	43.1	44.1	42.1	—3.1	—1.0	—2.0
.....	54.3	48.0	43.5	27.3	43.3							
nt F_1.....	53.4	38.4	44.3	27.6	40.9	45.2	43.3	44.2	40.9	—4.3	—2.4	—3.3
.....	52.9	43.3	48.2	26.5	42.7							
'ellow Dent F_1.....	54.7	31.1	44.6	26.0	39.1	45.2	42.7	43.9	39.1	—6.1	—3.6	—4.8
.....	42.4	26.0	51.0	23.0	35.6							
ue's Yellow Dent F_1..	39.5	35.5	43.0	28.5	36.6	45.2	35.6	40.4	36.6	—8.6	+1.0	—3.8
.....	50.7	43.4	40.8	25.5	40.1							
s Yellow Dent F_1.....	54.3	43.2	43.5	30.4	42.8	45.2	40.1	42.6	42.8	—2.4	+2.7	+0.2
.....	45.4	42.3	41.6	27.8	39.3							
Yellow Dent F_1.....	45.9	47.6	39.8	28.8	40.5	45.2	39.3	42.2	40.5	—4.7	+1.2	—1.7
.....	59.2	35.6	51.9	23.4	42.5							
gue's Yellow Dent F_1..	51.3	38.0	48.3	25.9	41.9	45.2	42.5	43.8	40.9	—4.3	—1.6	—2.9
.....	53.1	44.5	46.2	28.2	43.0							
Yellow Dent F_1.....	52.7	45.9	46.9	26.0	42.9	45.2	43.0	44.1	42.9	—2.3	—0.1	—1.2
.....	49.6	42.2	36.3	20.2	37.1							
w Dent F_1.....	53.1	40.2	47.2	24.2	41.2	45.2	37.1	41.1	41.2	—4.0	+4.1	0.0
.....	45.9	48.7	44.8	20.9	40.1							
's Yellow Dent F_1....	41.5	44.8	45.9	22.3	38.6	45.2	40.1	42.6	38.6	—6.6	—1.5	—4.0
.....	49.2	48.9	32.6	12.0	35.7							
s Yellow Dent F_1.....	52.4	51.8	46.6	18.6	42.3	45.2	35.7	40.4	42.3	—2.9	+6.6	+1.9
.....						45.2	40.5	42.8	41.2	—4.0	+0.7	—1.6

plicate each year except that there were fourteen plats of Hogue's Yellow Dent.
Female Parent.

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sults suggest that farmers in general would not increase their corn yields by exchanging seed with neighbors for the purpose of crossing with their own variety, except where seed selection has been so restricted that a measurable degree of close breeding has resulted.

TABLE 29.—*Summary showing comparison of F_1 hybrids and their parents. Average for thirteen hybrids for four years, 1914-1917.*

	Average of female parent	Average of male parent	Average of both parents	Average of hybrids	Deviation of hybrids from	
					Average of both parents	Highest yielding parent
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Date tasseling	7/30	8/1	7/31	8/1	+1	0.0
Date ripe	9/23	9/23	9/23	9/24	+1	+1.0
Days to maturity	53.8	53.0	53.4	53.9	+0.5	+0.9
Stalk height, inches	83.1	88.0	85.5	86.8	+1.3	—1.2
Ear height, inches	41.0	43.0	42.0	42.4	+0.4	—0.6
Suckers per 100 plants	10.0	24.0	17.0	15.0	—2	—9.0
Lodged per 100 plants	13.8	15.0	14.4	15.4	+1	+0.4
Ears per 100 plants	82.5	84.0	83.2	83.3	+0.1	—0.7
Two-eared plants, per 100	3.0	4.0	3.5	3.0	—0.5	—1.0
Shrinkage, per cent	8.5	10.2	9.3	9.7	+0.3	—0.5
Shelled corn, per cent	83.0	84.0	83.5	85.0	+1.5	+1.0
Yield per acre, bushels	40.5	45.2	42.8	41.2	—1.6	—4.0

FIRST, SECOND, AND THIRD GENERATIONS OF VARIETY HYBRIDS COMPARED

The comparative yields of the first and second generations of the variety hybrids are given in Table 30 for a three-year period, 1915-1917. Comparative yields for the first, second, and third generation hybrids are also given for the two-year period 1916-1917. The second and third generation crops did not deviate on an average more than 1.5 bushels from the F_1

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This is strikingly different from the results with pure line hybrids, where greatly reduced yields resulted from planting second or third generation seed, (see chart 2). This difference in behavior between pure line hybrids and variety hybrids in

TABLE 30.—*Comparison of first, second, and third generation variety hybrids with the parent averages. 1915-1917.*

Description	Yield per acre						
	3-year average, 1915-1917			2-year average, 1916-1917			
	F_1	F_2	Both parents	F_1	F_2	F_3	Both parents
(1)	*Bu.* (2)	*Bu.* (3)	*Bu.* (4)	*Bu.* (5)	*Bu.* (6)	*Bu.* (7)	*Bu.* (8)
Reid's × Hogue's	39.7	40.1	42.0	36.0	37.1	35.5	39.3
Iowa Gold Mine × Hogue's	39.4	35.9	39.4	34.5	34.3	35.6	36.2
Leaming × Hogue's	39.7	43.3	40.1	35.1	40.3	39.3	37.5
Calico × Hogue's	36.8	40.0	40.4	35.9	39.4	36.6	38.5
Bloody Butcher × Hogue's	33.9	35.9	39.8	35.3	33.5	30.3	38.3
U. S. S. Brush × Hogue's	35.7	38.7	36.8	35.7	38.3	37.6	38.1
St. Charles White × Hogue's	39.0	40.7	39.7	36.9	37.3	36.9	38.2
Iowa Silver Mine × Hogue's	38.7	40.3	40.0	34.3	39.7	36.9	38.9
Nebraska White Prize × Hogue's	37.4	37.3	39.0	37.1	35.4	39.7	39.1
Pride of the North × Hogue's	37.7	38.6	39.6	34.1	38.9	38.3	36.8
Minnesota No. 13 × Hogue's	39.0	36.2	36.7	32.6	31.3	28.7	32.3
White Cap × Hogue's	37.2	40.7	37.6	35.7	36.7	34.7	35.3
University No. 3 × Hogue's	39.6	40.0	39.9	36.4	37.3	30.3	38.2
General average	38.0	39.1	39.3	35.3	36.8	35.4	37.4

these later generations may be accounted for by the difference in the number of elemental strains represented in their basic composition. There is a cardinal difference between the behavior of second and later generations of pure line hybrids and that of variety hybrids. In these experiments the F_2 and F_3 variety hybrids and pure line hybrids were produced by close breeding a number of ears in the F_1 and F_2 generations respectively, with composite pollen from a number of plants. In regard to Mendelian factors, this corresponded to broad fertilization in the case of the former, and self-fertilization in the latter. The second generation seed was equivalent to composite seed as picked by a farmer from promiscuously pollinated fields of corn planted to first generation hybrids. Second and later generations lack the plant uniformity possessed by the first generation.

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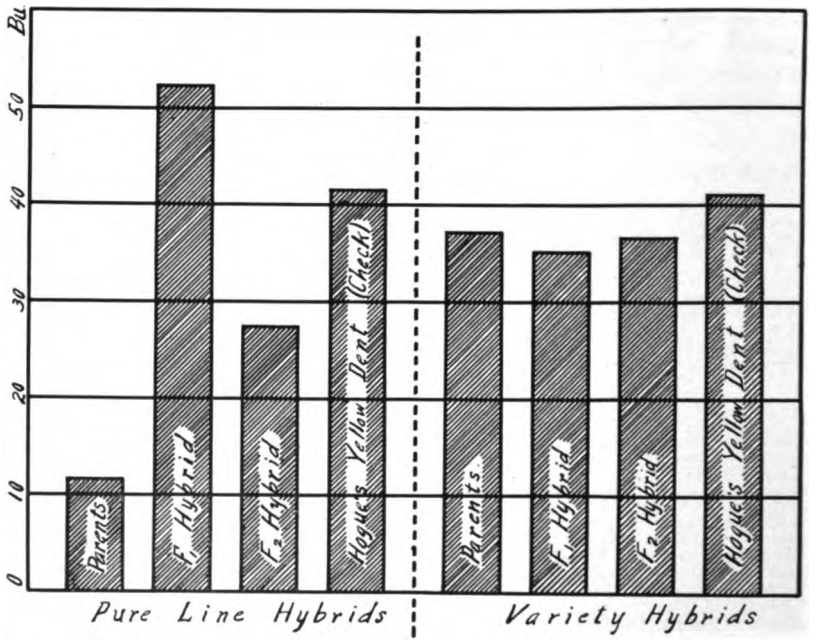

CHART 2.—Comparative effects of the crossing of pure lines (inbred) versus the crossing of commercial varieties. Average yields of grain per acre for seven pure line hybrids at left and thirteen variety hybrids at right. Data taken from Tables 14, 18, 25, 28, and 30 averaged for two years, 1916 and 1917. The 1917 yields for inbred parents are for composite planting and are taken from Table 25.

IMMEDIATE EFFECT OF FOREIGN POLLEN ON KERNEL WEIGHT

The study of the immediate effect of foreign pollen upon the weight of the corn kernel has aroused much interest. It is well known that the embryo of a kernel of corn is the direct product of the union of the male and female gametes. The

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Under what conditions and to what extent the kernel weight is influenced by the degree of kinship between pollen and ovules is not so well understood. It has been suggested by other investigators (1) that variety tests as commonly conducted, permitting promiscuous pollination between neighboring varieties, are unreliable because of the immediate effect of foreign pollen upon the yield and (2) that farmers may increase their yields by planting a mixture of varieties so that cross-pollination will occur. The theory upon which these statements are based is that the developing corn kernel receives an immediate stimulus thru being fertilized by foreign pollen. On this subject the following tests have been made at the Nebraska Experiment Station.

METHODS OF DETERMINATION

Since the effect of foreign pollen is confined to the individual kernels so fertilized, a direct comparison of hybrid and pure kernels on the same mature ear is possible. Pure, in this case, refers to kernels fertilized by pollen of the same variety, and hybrid refers to those fertilized by another variety. For experimental purposes, varieties are used which differ in endosperm color, so that the two sorts of kernels may be distinguished by the phenomenon of xenia.

This mixture of pure and hybrid kernels of known parentage may be produced either by planting two varieties in close proximity, thereby permitting natural mixing of pollen, or by artificially collecting, mixing, and applying the pollen to receptive silks which have been previously covered to avoid chance fertilization.

The method of comparing the weights of pure and hybrid kernels on the same ear has been commonly employed by other investigators and has been used in these investigations. The number and location of the hybrid kernels upon the ear is more or less a matter of chance. On some ears they are uniformly scattered thru the ear (fig. 21); on others they will tend to be localized in certain portions of the ear. Since the kernels usually become systematically smaller with an approach toward the tip of the ear, it is apparent that precautions must be taken to avoid experimental errors easily resulting from place effect on the ear. Pure and hybrid kernels should, for comparison, be removed in adjacent pairs. Thus the hybrid kernel should be taken for the test only when there is an adjacent pure kernel in the same row, which may also be removed. If a high degree of accuracy is desired, equal numbers of pure kernels should

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be taken from the butt and tip sides of the hybrid kernels used. This will overcome the systematic reduction in kernel size toward the ear tip which is associated with the natural tapering of the ear.

In a test with four varieties, the average reduction in kernel weight from butt to tip was one per cent for each successive kernel.

In an endeavor to determine the effect of foreign pollen

TABLE 31.—*Illustrating the method of determining the immediate effect of foreign pollen upon kernel size by comparing the hybrid kernels with all pure kernels on an ear of corn versus the method of comparing them in adjacent pairs. 1921.*

Ear No.	Hybrid kernels mostly located at	Pure and hybrid kernels compared only in pairs			
		No. of kernels of each sort	Weight of 100 kernels		Ratio of hybrid to pure
			Pure	Hybrid	
(1)	(2)	(3)	*Grams* (4)	*Grams* (5)	*Per cent* (6)
1	Tip of ear	174	18.45	18.40	99.73
2	Middle of ear	72	26.89	26.94	100.19
3	Butt of ear	204	19.98	20.36	101.90
4	Generally distributed	153	33.25	33.63	101.14

Ear No.	All hybrid kernels on ear contrasted with all pure kernels				
	No. of kernels of each sort		Weight of 100 kernels		Ratio of hybrid to pure
	Pure	Hybrid	Pure	Hybrid	
(1)	(7)	(8)	*Grams* (9)	*Grams* (10)	*Per cent* (11)
1	591	276	24.72	18.15	73.42
2	418	328	26.67	27.21	102.02
3	342	574	19.22	21.51	111.91
4	548	173	33.91	33.61	99.12

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upon kernel weight, a large number of ears should be used to overcome variation in the degree of reaction to cross-pollination by individual ears. The method of comparing pure and hybrid kernels in pairs has been found far superior at this Station (Table 31) to that of contrasting hybrid kernels with all the pure kernels grown on the same ear.

In the case of two varieties: (1) When the hybrid kernels were largely localized on the tip third portion of the ear and all were compared as to average kernel weight with all the pure kernels on the ear, the average weight of hybrid kernels was 26.58 per cent less than that of the pure kernels; whereas, when removed in pairs the hybrid kernels weighed only 0.27 per cent less than the pure. (2) When the hybrid kernels were largely localized on the butt third of the ear, their weight exceeded that of the pure kernels by 11.91 per cent when compared by the former method, and by only 1.90 per cent when taken in pairs. (3) When the hybrid kernels were largely localized on the middle third of the ear, the hybrid kernels outweighed the pure by 2.02 per cent when the former method was used and by only 0.19 per cent when taken out in pairs. (4) When the hybrid kernels were quite generally distributed thru the ear, their average weight was 0.88 per cent less than that of the pure when compared by the former method and 1.14 per cent more when removed in pairs. When all the hybrid kernels were contrasted with all the pure kernels on each ear, the variation in weight, for all ears, of the hybrid kernels was from 26.58 per cent less to 11.91 per cent more than that of the pure; and when the kernels were removed from each ear in pairs, the extreme range of variation in weight of the hybrid kernels for the various ears used was from 0.27 per cent less to 1.90 per cent more than the pure.

RESULTS WITH VARIETIES

During five years (Table 32) a large number of ordinary Hogue's Yellow Dent ears were selected which had been grown near a field of Nebraska White Prize corn and were therefore subject to partial cross-fertilization. The hybrid and pure kernels were removed in pairs only and the two groups

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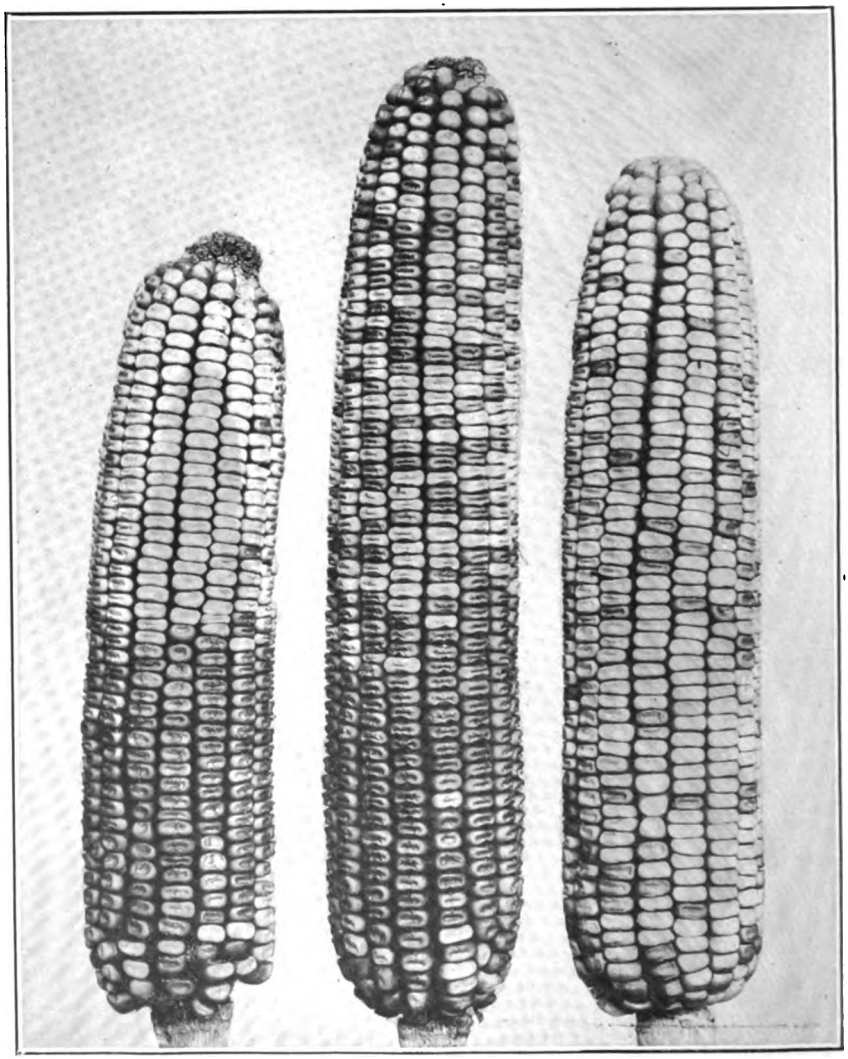

FIG. 21.—Ears of Hogue's Yellow Dent corn partially fertilized by Nebraska White Prize. The pure and hybrid kernels may easily be separated, because of xenia, in a study of the immediate effect of foreign pollen on kernel weight. These ears illustrate the possibility of experimental error in such studies resulting from place effect in the unequal distribution of pure and hybrid kernels thruout the ear. This place effect may be largely overcome by comparing such kernels in adjacent pairs only.

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TABLE 32.—*Immediate effect of foreign pollen upon kernel weight of an ordinary variety of dent corn. Five years, 1914-1917 and 1920.*

Year	Kind of kernels	Number of kernels in test	Weight of 1000 kernels (moisture free)		Difference in weight of 1000 kernels	
			Actual	Relative		
(1)	(2)	(3)	*Grams* (4)	*Per cent* (5)	*Grams* (6)	*Per cent* (7)
1914....	Pure.....	5,000	307.8	100.0		
	Hybrid.....	5,000	313.4	101.8	+5.6	+1.8
1915....	Pure.....	10,177	246.1	100.0		
	Hybrid.....	10,177	249.3	101.3	+3.2	+1.3
1916....	Pure.....	9,405	272.0	100.0		
	Hybrid.....	9.405	271.5	99.8	—0.5	—0.2
1917....	Pure.....	8,435	281.7	100.0		
	Hybrid.....	8,435	279.8	99.3	—1.9	—0.7
1920....	Pure.....	5,000	259.6	100.0		
	Hybrid.....	5,000	257.8	99.3	—1.8	—0.7

As a five-year average, the hybrid kernels weighed 0.32 per cent more than the pure.

The hybrid kernels were Hogue's Yellow Dent fertilized by Nebraska White Prize corn.

The pure kernels were Hogue's Yellow Dent.

This is equal to one bushel increase in every 312 bushels hybrid grain. The data suggest that the gametes which unite to produce the kernels within an ordinary variety of dent corn are already so unrelated that the vigor which they impart is only very slightly exceeded by introducing foreign Mendelian factors thru the pollen of another dent variety. This conclusion is further substantiated by the data for 1921 with miscellaneous varie-

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TABLE 33.—*Immediate effect of foreign pollen upon kernel weight of five ordinary varieties of dent corn. 1921.*

Ear No.	Number of kernels of each sort	Weight of 100 kernels			
		Actual		Relative	
		Pure	Hybrid	Pure	Hybrid
(1)	(2)	*Grams* (3)	*Grams* (4)	*Per cent* (5)	*Per cent* (6)
MARTENS' WHITE DENT PARTLY FERTILIZED BY MINNESOTA NO. 13					
1	89	27.68	28.00	100	101.16
2	72	27.79	28.13	100	101.22
3	70	27.63	28.03	100	101.45
Average				100	101.27
MINNESOTA NO. 13 PARTLY FERTILIZED BY MARTENS' WHITE DENT					
1	29	18.20	18.10	100	99.45
2	24	36.15	35.88	100	99.25
3	35	27.43	27.52	100	100.33
Average				100	99.68
BOONE COUNTY WHITE PARTLY FERTILIZED BY REID'S YELLOW DENT					
1	101	25.08	24.40	100	97.29
2	91	27.80	27.68	100	99.57
3	198	29.96	29.47	100	98.36
Average				100	98.41
REID'S YELLOW DENT PARTLY FERTILIZED BY COMMERCIAL WHITE					
1	117	33.36	33.95	100	101.77
2	95	33.37	33.86	100	101.47
3	146	32.88	32.29	100	98.21
Average				100	100.48
HOGUE'S YELLOW DENT PARTLY FERTILIZED BY COMMERCIAL WHITE					
1	36	20.33	20.56	100	101.13
2	44	36.73	36.68	100	99.86
3	75	28.65	29.01	100	101.26
Average				100	100.75
Average for all varieties				100	100.12

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Prize. (4) Pure line Nebraska White Prize ears fertilized by a mixture of pollen from pure line sister plants and from standard Hogue's Yellow Dent. (5) Ordinary standard Hogue's Yellow Dent ears fertilized by a mixture of pollen from the same variety and from Nebraska White Prize pure lines. (6) Standard Nebraska White Prize ears fertilized by a mixture from the same variety and from Hogue's Yellow Dent pure lines. (7) Hogue's Yellow Dent ears fertilized by a mixture of pollen from the same variety and from standard Nebraska White Prize. (8) Standard Nebraska White Prize ears fertilized by a mixture of pollen from the same variety and from standard Hogue's Yellow Dent.

The number of ears available for the pure line combinations is so small that the increase in weight due to foreign pollen may not be typical in exact degree, tho the general indication is correct. The results are given in Table 34 and are summarized together with other 1921 data in Table 35.

Hybrid kernels on Hogue's Yellow Dent pure line ears fertilized with pollen from Nebraska White Prize pure lines weighed 16.15 per cent heavier than the pure kernels.

Hybrid kernels on Nebraska White Prize pure line ears fertilized with pollen from Hogue's Yellow Dent pure lines weighed 10.87 per cent heavier than the pure kernels.

Hybrid kernels on Hogue's Yellow Dent pure line ears fertilized with pollen from the ordinary commercial variety of Nebraska White Prize corn weighed 6.97 per cent heavier than the pure kernels.

Hybrid kernels on Nebraska White Prize pure line ears which had been fertilized with pollen from standard Hogue's Yellow Dent weighed 10.65 per cent heavier than the pure kernels.

Hybrid kernels on ordinary commercial Hogue's Yellow Dent ears fertilized by Nebraska White Prize pure lines weighed 0.73 per cent less than the pure kernels.

Hybrid kernels on ordinary commercial Nebraska White Prize ears fertilized by Hogue's Yellow Dent pure lines weighed 0.64 per cent heavier than the pure kernels.

Hybrid kernels on ordinary commercial Hogue's Yellow Dent ears fertilized by ordinary commercial Nebraska White Prize weighed 1.09 per cent heavier than the pure kernels.

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TABLE 34.—*Immediate effect of foreign pollen upon kernel weight of inbred pure lines versus original varieties. 1921.*

Ear No.	Number of kernels of each sort	Weight of 100 kernels			
		Actual		Relative	
		Pure	Hybrid	Pure	Hybrid
(1)	(2)	*Grams* (3)	*Grams* (4)	*Per cent* (5)	*Per cent* (6)
INBRED NEBRASKA WHITE PRIZE PARTLY FERTILIZED BY INBRED HOGUE'S YELLOW DENT					
1	71	29.24	31.99	100	109.40
2	86	25.48	28.31	100	111.11
3	41	27.20	30.73	100	112.98
4	68	28.92	31.79	100	109.92
5	109	25.96	29.17	100	112.37
6	39	29.84	32.91	100	110.29
7	35	23.72	26.92	100	113.49
8	52	30.23	31.68	100	104.80
9	30	18.17	20.88	100	114.91
10	116	19.03	20.83	100	109.46
Average					110.87
INBRED NEBRASKA WHITE PRIZE PARTLY FERTILIZED BY STANDARD HOGUE'S YELLOW DENT					
1	51	13.63	14.24	100	104.48
2	17	14.30	14.52	100	101.54
3	11	9.06	10.19	100	112.47
4	24	16.14	16.87	100	104.52
5	21	9.84	11.44	100	116.26
6	11	9.14	10.63	100	116.30
7	43	19.87	20.91	100	105.23
8	8	10.67	11.72	100	109.84
9	14	8.61	9.96	100	115.68
10	19	9.69	11.63	100	120.14
Average					110.65
STANDARD NEBRASKA WHITE PRIZE PARTLY FERTILIZED BY INBRED HOGUE'S YELLOW DENT					
1	33	36.24	36.08	100	99.56
2	13	29.42	30.11	100	102.35
3	44	25.20	25.49	100	101.15
4	105	19.59	19.46	100	99.34
5	89	21.65	21.59	100	99.72
6	26	26.69	27.29	100	102.25
7	11	33.86	34.32	100	101.36
8	87	25.06	24.90	100	99.36
Average					100.64
STANDARD NEBRASKA WHITE PRIZE PARTLY FERTILIZED BY STANDARD HOGUE'S YELLOW DENT					
1	117	19.37	18.88	100	97.47
2	103	23.30	23.15	100	99.36
3	122	15.64	15.72	100	100.51
4	64	18.85	19.37	100	102.76
5	86	19.91	19.18	100	96.33
6	22	24.09	24.66	100	102.37
7	117	15.93	15.81	100	99.25
8	73	30.84	30.97	100	100.42

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TABLE 34 CONCLUDED.—*Immediate effect of foreign pollen upon kernel weight of inbred pure lines versus original varieties. 1921.*

Ear No.	Number of kernels of each sort	Weight of 100 kernels			
		Actual		Relative	
		Pure	Hybrid	Pure	Hybrid
(1)	(2)	*Grams* (3)	*Grams* (4)	*Per cent* (5)	*Per cent* (6)
INBRED HOGUE'S YELLOW DENT PARTLY FERTILIZED BY INBRED NEBRASKA WHITE PRIZE					
1	9	21.94	25.47	100	116.09
2	7	26.05	29.98	100	115.09
3	7	23.94	26.84	100	112.11
4	8	21.37	25.90	100	121.20
5	12	21.17	24.61	100	116.25
Average					116.15
INBRED HOGUE'S YELLOW DENT PARTLY FERTILIZED BY STANDARD NEBRASKA WHITE PRIZE					
1	15	23.98	24.79	100	103.38
2	52	16.80	19.14	100	113.93
3	35	20.60	22.07	100	107.14
4	18	21.07	21.49	100	101.99
5	47	22.49	24.38	100	108.40
Average					106.97
STANDARD HOGUE'S YELLOW DENT PARTLY FERTILIZED BY INBRED NEBRASKA WHITE PRIZE					
1	8	14.44	14.34	100	99.31
2	130	30.19	30.10	100	99.70
3	86	25.78	26.03	100	100.97
4	37	36.69	35.62	100	97.08
Average					99.27
STANDARD HOGUE'S YELLOW DENT PARTLY FERTILIZED BY STANDARD NEBRASKA WHITE PRIZE					
1	229	27.62	27.98	100	101.30
2	137	25.73	25.80	100	100.27
3	125	29.52	30.08	100	101 90
4	271	27.99	28.62	100	102.25
5	216	26.87	27.43	100	102.08
6	192	26.90	27.58	100	102.53
7	191	34.82	35.08	100	100.75
8	242	24.26	24.34	100	100.33
9	246	22.07	22.12	100	100.23
10	216	23.45	23.56	100	100.47
11	164	20.73	20.78	100	100.24
12	151	22.15	22.32	100	100.77
Average					101.09

Taking all of the data into consideration, it may be concluded that no material increase in weight results from fertiliz-

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TABLE 35.—*Summary showing immediate effect of foreign pollen upon kernel weight of dent corn. 1921.*[1]

No. of ears av.	Female parent	Male parent	Ratio weight of hybrid kernels to pure
			Per cent
	EARS BORNE ON INBRED PURE LINE PLANTS		
10	Inbred Nebraska White Prize	Inbred Hogue's Yellow Dent	110.87
5	Inbred Hogue's Yellow Dent	Inbred Nebraska White Prize	116.15
10	Inbred Nebraska White Prize	Ordinary Hogue's Yellow Dent	110.65
5	Inbred Hogue's Yellow Dent	Ordinary Nebraska White Prize	106.97
30	Average		111.16
	EARS BORNE ON PLANTS OF ORDINARY VARIETIES		
12	Nebraska White Prize	Hogue's Yellow Dent	99.90
12	Hogue's Yellow Dent	Nebraska White Prize	101.09
3	Martens' White Dent	Minnesota No. 13	101.27
3	Minnesota No. 13	Martens' White Dent	99.68
3	Boone County White	Reid's Yellow Dent	98.41
3	Reid's Yellow Dent	Commercial White	100.48
3	Hogue's Yellow Dent	Commercial White	100.75
39	Average		100.22
8	Nebraska White Prize	Inbred Hogue's Yellow Dent	100.64
4	Hogue's Yellow Dent	Inbred Nebraska White Prize	99.27
12	Average		99.95

[1]Data compiled from Tables 33 and 34.

Pollen from an unrelated homozygous plant has as much influence upon kernel size as pollen from a heterozygous plant.

Varieties or strains which have undergone very close selection for type or have by some other means been somewhat restricted in the number of Mendelian factors represented in their hereditary constitution might reasonably be expected to respond in a slight degree to foreign pollen.

With broad, wind fertilized varieties, the slight average increase of 0.22 per cent in kernel weight due to foreign pollen can doubtless be accounted for in part by the fact that absolutely none of the hybrid kernels were selfed; while, as has been shown earlier, a small portion, approximately 0.7 per cent, of the kernels in a field were selfed in ordinary wind fertilization.

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The studies of the comparative effects of foreign pollen have by no means been exhaustive, and further investigations are suggested. The entire problem is so involved that these data are merely offered as a report of progress.

RELATIVE EFFECTS OF FOREIGN POLLEN UPON EMBRYO AND ENDOSPERM WEIGHTS OF INBRED CORN

The preceding data indicate so clearly an increase in kernel weight resulting from fertilization of homozygous (inbred) corn with foreign pollen that it becomes a matter of interest to know the relative effect upon the various parts of the kernel. A grain of corn consists of three main portions, (1) the seed coat (pericarp), (2) the endosperm or starchy portion, and (3) the embryo. The seed coat is a portion of the mother plant and can be only indirectly influenced by the character of the pollen.

The separation of the kernels into their component parts was facilitated by soaking them in water for 24 hours. This was preceded by heating at 100° C. to destroy the viability and thereby avoid any growth changes due to supplying moisture. After dissection, the respective portions were rendered moisture free at 105° C. and weighed. Pure line strains of both Hogue's Yellow Dent and Nebraska White Prize reported in Table 34 were used in these tests. A very brief study was also made with ordinary corn of these two varieties for the purpose of general comparison. The results are given in Table 36 and summarized in Table 37 and chart 3.

The manner of obtaining comparable pure and hybrid kernels has been previously described. As an average for the pure lines of both varieties, the immediate effect of foreign pollen was to increase the weight of (1) the kernel 11.09 per cent, (2) the embryo 20.22 per cent, (3) the endosperm 10.39 per cent, and (4) the seed coat 5.36 per cent. In contrast, kernels of ordinary heterozygous corn were not materially influenced in the development of their respective parts by fertilization with foreign pollen.

The ratio of embryo to endosperm weight is nearly the same for the kernels borne on ordinary heterozygous variety plants as for the pure kernels on pure line plants derived by inbreeding. This suggests that the embryo and endosperm reduce to about the same degree as a result of continued self-fertilization. The proportion of embryo to endosperm is somewhat greater in cross-pollinated than in pure kernels borne on pure line plants.

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TABLE 36.—*Immediate effect of foreign pollen on the relative development of different parts of the kernels of pure line (inbred) corn (Hogue's Yellow Dent and Nebraska White Prize corn). 1921.*

Ear No.	Kind of kernels	Number of kernels	Moisture free weights of				Ratio of embryo to endosperm
			Kernels	Embryos	Endosperms	Seed coats	
			Grams	*Grams*	*Grams*	*Grams*	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
INBRED HOGUE'S YELLOW DENT PARTLY FERTILIZED BY NEBRASKA WHITE PRIZE							
1	Pure	9	1.9748	0.2232	1.6477	0.1038	0.1355
	Hybrid	9	2.2924	0.2906	1.8879	0.1139	0.1539
	Ratio		1.1608	1.3020	1.1458	1.0973	1.1358
2	Pure	7	1.8236	0.1826	1.5532	0.0878	0.1176
	Hybrid	7	2.0985	0.2454	1.7605	0.0926	0.1394
	Ratio		1.1507	1.3439	1.1335	1.0547	1.1854
3	Pure	7	1.6758	0.1741	1.4133	0.0886	0.1232
	Hybrid	7	1.8785	0.2270	1.5593	0.0922	0.1456
	Ratio		1.1209	1.3038	1.1033	1.0406	1.1818
4	Pure	8	1.7093	0.1801	1.4398	0.0894	0.1251
	Hybrid	8	2.0724	0.2398	1.7326	0.1000	0.1384
	Ratio		1.2124	1.3315	1.2034	1.1186	1.1063
5	Pure	12	2.5409	0.2726	2.1325	0.1358	0.1278
	Hybrid	12	2.9535	0.3569	2.4478	0.1488	0.1458
	Ratio		1.1624	1.3092	1.1479	1.0957	1.1408
6	Pure	15	3.5965	0.3523	3.0679	0.1763	0.1148
	Hybrid	15	3.7187	0.3768	3.1554	0.1865	0.1194
	Ratio		1.0340	1.0695	1.0285	1.0578	1.0401
7	Pure	52	8.7381	0.7834	7.5109	0.4442	0.1043
	Hybrid	52	9.9526	1.0692	8.4028	0.4806	0.1272
	Ratio		1.1390	1.3648	1.1187	1.0819	1.2196
8	Pure	35	7.2108	0.7035	6.1793	0.3380	0.1138
	Hybrid	35	7.7258	0.8394	6.5221	0.3641	0.1287
	Ratio		1.0714	1.1932	1.0555	1.0772	1.1309
9	Pure	18	3.7922	0.3820	3.2062	0.2020	0.1191
	Hybrid	18	3.8690	0.3985	3.2614	0.2091	0.1222
	Ratio		1.0202	1.0432	1.0172	1.0351	1.0260
	Pure	47	10.5694	1.0506	9.0944	0.4244	0.1155
	Hybrid	47	11.4583	1.1885	9.7763	0.4535	0.1216
	Ratio		1.0841	1.1313	1.0750	1.0686	1.0528
	Average of ratios		1.1156	1.2392	1.1029	1.0728	1.1219

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TABLE 36 CONCLUDED.—*Immediate effect of foreign pollen on the relative development of different parts of the kernels of pure line (inbred) corn. 1921.*

Ear No.	Kind of kernels	Number of kernels	Moisture free weights of				Ratio of embryo to endosperm
			Kernels	Embryos	Endosperms	Seed coats	
(1)	(2)	(3)	*Grams* (4)	*Grams* (5)	*Grams* (6)	*Grams* (7)	(8)
INBRED NEBRASKA WHITE PRIZE PARTLY FERTILIZED BY HOGUE'S YELLOW DENT							
1	Pure	51	6.9526	0.8081	5.7566	0.3879	0.1404
	Hybrid	51	7.2600	0.8250	6.0413	0.3937	0.1366
	Ratio		1.0442	1.0209	1.0495	1.0150	0.9729
2	Pure	17	2.4316	0.2598	2.0330	0.1388	0.1278
	Hybrid	17	2.4677	0.2688	2.0542	0.1447	0.1309
	Ratio		1.0148	1.0346	1.0104	1.0425	1.0243
3	Pure	11	0.9971	0.1155	0.8098	0.0718	0.1426
	Hybrid	11	1.1204	0.1371	0.9141	0.0692	0.1500
	Ratio		1.1237	1.1870	1.1288	0.9638	1.0519
4	Pure	24	3.8747	0.4671	3.2062	0.2014	0.1457
	Hybrid	24	4.0498	0.5010	3.3393	0.2095	0.1500
	Ratio		1.0452	1.0726	1.0415	1.0402	1.0295
5	Pure	21	2.0656	0.1708	1.7390	0.1558	0.0982
	Hybrid	21	2.4030	0.2227	2.0131	0.1672	0.1106
	Ratio		1.1633	1.3039	1.1576	1.0732	1.1263
6	Pure	11	1.0054	0.1067	0.8304	0.0683	0.1285
	Hybrid	11	1.1694	0.1439	0.9524	0.0731	0.1511
	Ratio		1.1631	1.3486	1.1469	1.0703	1.1759
7	Pure	43	8.5430	0.9147	7.0237	0.6046	0.1302
	Hybrid	43	8.9897	1.0200	7.3966	0.5731	0.1379
	Ratio		1.0523	1.1151	1.0531	0.9479	1.0591
8	Pure	8	0.8534	0.0877	0.7138	0.0519	0.1229
	Hybrid	8	0.9379	0.0912	0.7857	0.0610	0.1161
	Ratio		1.0990	1.0399	1.1007	1.1753	0.9447
9	Pure	14	1.2050	0.1184	1.0102	0.0764	0.1172
	Hybrid	14	1.3940	0.1488	1.1666	0.0766	0.1276
	Ratio		1.1568	1.2568	1.1548	1.0026	1.0887
10	Pure	19	1.8400	0.1822	1.5370	0.1208	0.1185
	Hybrid	19	2.2100	0.2320	1.8556	0.1224	0.1250
	Ratio		1.2011	1.2733	1.2073	1.0132	1.0549
	Average of ratios		1.1063	1.1653	1.1051	1.0344	1.0528

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TABLE 37.—*Summary of immediate effect of foreign pollen on the relative development of different parts of the corn kernel (Hogue's Yellow Dent and Nebraska White Prize). 1921.*

Ear-bearing parent	Pollen parent	Kind of kernels	No. of ears tested	Relative weights				Ratio of embryo weight to endosperm weight
				Kernel	Embryo	Endosperm	Seed coat	
(1)	(2)	(3)	(4)	*Per cent* (5)	*Per cent* (6)	*Per cent* (7)	*Per cent* (8)	(9)
EARS BORNE ON PURE LINE (INBRED) PLANTS								
Inbred Hogue's Yellow Dent	Nebraska White Prize	Pure	10	100.00	100.00	100.00	100.00	.1197
		Hybrid	10	111.55	123.92	110.29	107.28	.1342
Inbred Nebraska White Prize	Hogue's Yellow Dent	Pure	10	100.00	100.00	100.00	100.00	.1272
		Hybrid	10	110.63	116.53	110.50	103.44	.1336
Average, both varieties		Pure	20	100.00	100.00	100.00	100.00	.1234
		Hybrid	20	111.09	120.22	110.39	105.36	.1339
EARS BORNE ON PLANTS OF ORDINARY VARIETIES								
Average of Hogue's Yellow Dent and Nebraska White Prize		Pure	4	100.00	100.00	100.00	100.00	.1275
		Hybrid	4	100.16	101.31	100.18	99.00	.1295

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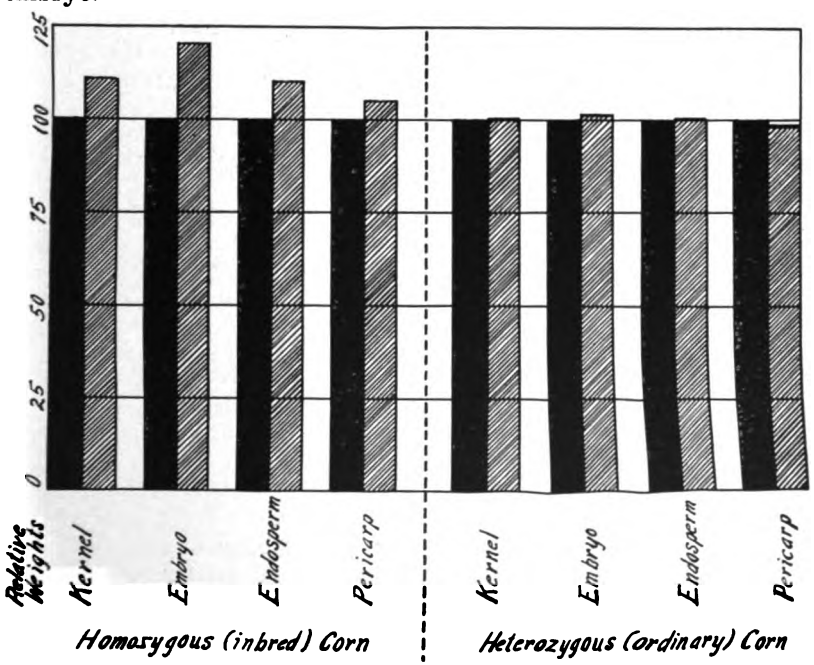
The relatively greater immediate increase in weight of the embryo than of the endosperm upon crossing elemental strains would necessarily seem to be due either to the difference in chromosome relationships within the two parts or else to a difference in their relative nutrition.

The cause of the difference in relative development seems more likely a matter of nutrition. The small leaf area, reduced root development, and sluggish synthetic activities of the inbred plant may result in a somewhat undersupply of plant nutrients. In such event, the full development of the embryo, which is the vital element in reproduction, might be favored at the expense of the endosperm. The endosperm is a mere food supply for the embryo and may be somewhat more heavily drawn upon even at this stage as a result of the stimulated growth of the embryo.



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HISTOLOGICAL EFFECTS OF INBREEDING

The hybridization of elemental strains of corn is so commonly attended with marked increase in plant size that it becomes a matter of interest to know how this is related to cell development—the cell being the unit of plant structure.

The data in Table 38, showing the relative number and size of certain histological units, covers seven pure lines and ten F_1 hybrids in which all seven pure lines are represented. Histological material was gathered from four representative plants of each pure line or hybrid at about the silking period. The corn had attained its full vegetative development by this time. Material for stalk sectioning was taken midway of the first internode above the ground. Material for leaf study was taken at the widest portion of the main ear leaf midway between the midrib and the margin. In order to overcome the great variability among the different units, a large number of individual counts and measurements were taken for each strain. In the case of stalk sections, fifty independent observations were made for each character under consideration. In case of leaf measurements, this number was increased to 100. All of these microscopic observations were made with unstained material preserved in alcohol.

The data as taken are considered as indicative of the histological differences which occur between pure lines and their hybrids. Plant individuality and limited amount of material may account for some of the irregularity and apparent inconsistencies which occur in a few instances. These are probably fairly well eliminated in the averages for all the pure lines as opposed to the averages for all the hybrids.

Comparing the hybrid with the average of its two parents, (1) the stalk diameter was 46 per cent greater, (2) the total number of fibrovascular bundles in a cross section of the stalk was 45 per cent greater, (3) the number of vascular bundles in

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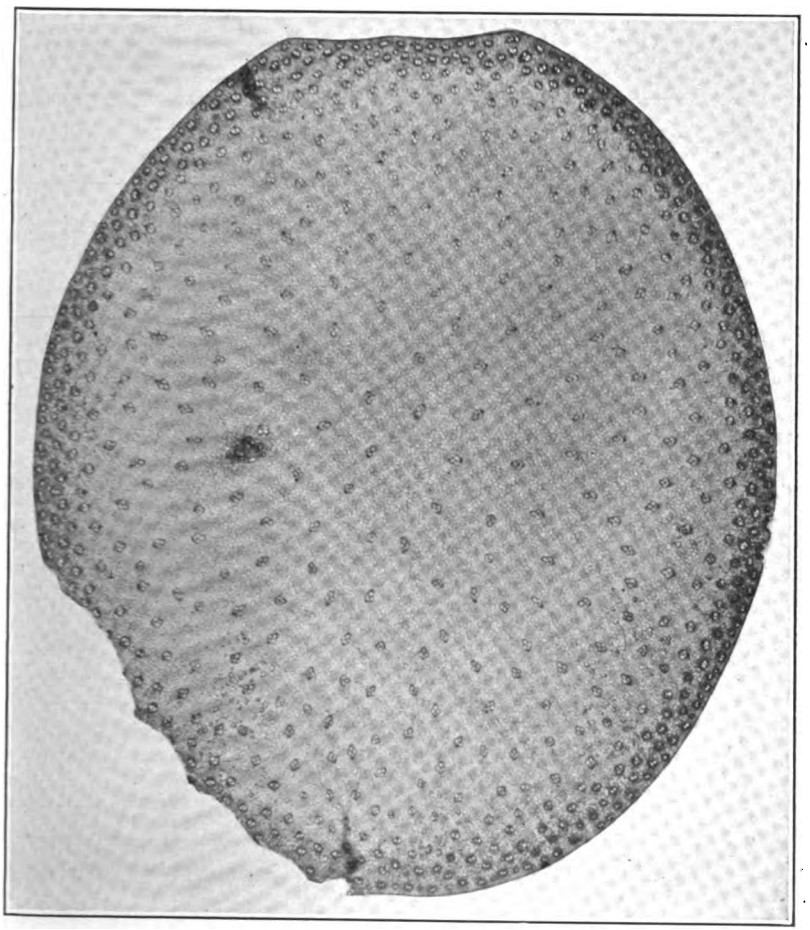

FIG. 22.—Cross section of a full-grown cornstalk near base, showing cellular structure and arrangement of vascular bundles. Enlarged five diameters. The effects of inbreeding and crossing on these and other histological units are given in Table 38.

In cross section of the stalk near base, ten hybrids compared with their pure line parents averaged approximately 117 per cent greater area, 92 per cent more pith cells, 46 per cent more vascular bundles, 8 per cent greater pith cell diameter, and 15 per cent greater bundle diameter.

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iparative histological development of elemental strains and their first generation hybrids. Hogue's Yellow Dent corn. 1916.

	Stalk								Leaf			
ter	No. of bundles in stalk	No. of bundles in one sq. cm.	No. of bundles in one diameter	No. of bundles in one cm. diameter	Diameter of bundle	No. of pith cells in diameter	Diameter of one pith cell	Length of pith cell	Thickness of leaf	Average thickness of upper and lower epidermis	No. of vascular bundles in one cm.	Average width of epidermal cell, lower and upper epidermis
					Microns		*Microns*	*Microns*	*Microns*	*Microns*		*Microns*
	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	449	174.6	5.8	3.16	309.9	154.6	105.8	154.2	193.8	29.4	67.5	36.3
	404	186.7	6.0	3.60	302.2	142.5	103.1	134.9	186.7	32.2	69.7	33.3
	426	180.6	5.9	3.38	306.0	148.5	104.4	144.5	190.2	30.8	68.6	34.8
	621	100.0	7.1	2.52	392.8	196.8	129.0	158.0	207.5	33.0	62.0	40.0
7	1.458	0.554	1.203	0.746	1.284	1.325	1.236	1.093	1.091	1.071	0.904	1.149
	449	174.6	5.8	3.16	309.9	154.6	105.8	154.2	193.8	29.4	67.5	36.3
	373	161.8	4.1	2.34	279.5	145.4	111.0	162.6	208.1	33.3	78.5	33.5
	411	168.2	4.9	2.75	294.7	150.0	108.4	158.4	200.9	31.3	73.0	34.9
	730	134.2	6.8	2.57	353.2	197.4	133.5	161.2	244.1	32.5	66.4	35.4
3	1.776	0.798	1.388	0.935	1.199	1.316	1.232	1.018	1.215	1.038	0.910	1.014
	543	198.4	6.2	3.34	279.9	140.3	120.5	162.4	205.5	33.6	66.3	37.3
	466	237.0	4.6	2.92	279.2	135.9	107.9	163.2	207.9	34.8	76.1	34.0
	504	217.7	5.4	3.13	279.5	138.1	114.2	162.8	206.7	34.2	71.2	35.6
	772	130.7	7.1	2.57	357.2	225.3	110.6	167.3	237.4	34.5	65.8	37.1
5	1.532	0.600	1.315	0.821	1.278	1.631	0.968	1.028	1.149	1.009	0.924	1.042
	543	198.4	6.2	3.34	279.9	140.3	120.5	162.4	205.5	33.6	66.3	37.3
	629	135.7	6.2	2.55	305.4	185.7	120.9	154.5	193.7	26.9	70.6	31.0
	586	167.0	6.2	2.94	292.6	163.0	120.7	158.4	199.6	30.2	68.4	34.1
	857	125.0	7.3	2.46	343.6	223.7	120.2	182.0	242.1	31.4	60.0	37.1
2	1.462	0.749	1.177	0.837	1.174	1.372	0.996	1.149	1.213	1.040	0.877	1.088
	404	186.7	6.0	3.60	302.2	142.5	103.1	134.9	186.7	32.2	69.7	33.3
	629	135.7	6.2	2.55	305.4	185.7	120.9	154.5	193.7	26.9	70.6	31.0
	516	161.2	6.1	3.07	303.8	164.1	112.0	144.7	190.2	29.5	70.1	32.1
	652	103.6	6.0	2.11	349.0	220.5	112.4	176.3	209.1	31.4	63.2	32.8
)	1.264	0.643	0.984	0.687	1.149	1.344	1.004	1.218	1.099	1.064	0.902	1.022

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TABLE 38 CONCLUDED.—*Comparative histological development of elemental strains and their first generation hybrids. Hogue's Yellow Dent corn. 1916.*

Pure line No.	Stalk									Leaf			
	Diameter of stalk	No. of bundles in stalk	No. of bundles in one sq. cm.	No. of bundles in one diameter	No. of bundles in one cm. diameter	Diameter of bundle	No. of pith cells in diameter	Diameter of one pith cell	Length of pith cell	Thickness of leaf	Average thickness of upper and lower epidermis	No. of vascular bundles in one cm.	Average width of epidermal cell, lower and upper epidermis
	Mm.					*Microns*		*Microns*	*Microns*	*Microns*	*Microns*		*Microns*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
5	21.2	510	145.2	5.9	2.84	327.0	177.3	108.0	191.4	209.5	28.6	62.6	34.4
10	16.1	466	237.0	4.6	2.92	279.3	135.8	107.9	163.2	207.9	34.8	76.1	34.0
Average	18.6	488	191.1	5.2	2.88	303.1	156.5	107.9	177.3	208.7	31.7	69.3	34.2
10 × 5 F_1	27.9	685	112.7	6.6	2.43	319.0	229.3	110.3	220.1	230.3	32.6	67.4	34.2
Ratio	1.500	1.404	0.590	1.269	0.844	1.052	1.465	1.022	1.241	1.103	1.028	0.973	1.000
5	21.2	510	145.2	5.9	2.84	327.0	177.3	108.0	191.4	209.5	28.6	62.6	34.4
12	24.3	629	135.7	6.2	2.55	305.4	185.7	120.9	154.5	193.7	26.9	70.6	31.0
Average	22.7	569	140.4	6.0	2.69	316.2	181.5	114.4	172.9	201.6	27.7	66.6	32.7
12 × 5 F_1	34.1	852	93.5	6.6	1.93	340.2	232.0	137.2	179.4	236.2	29.8	63.7	32.7
Ratio	1.502	1.497	0.666	1.100	0.717	1.076	1.278	1.199	1.038	1.172	1.076	0.956	1.000
8	17.7	373	161.8	4.1	2.34	279.5	145.4	111.0	162.6	208.1	33.3	78.5	33.5
10	16.1	466	237.0	4.6	2.92	279.2	135.9	107.9	163.2	207.0	34.8	76.1	34.0
Average	16.9	419	199.4	4.3	2.63	279.3	140.6	109.4	162.9	208.0	34.0	77.3	33.7
8 × 10 F_1	23.3	560	132.2	5.0	2.16	297.6	186.0	117.4	161.6	218.5	34.0	78.1	35.3
Ratio	1.379	1.337	0.663	1.163	0.821	1.066	1.323	1.073	0.992	1.050	1.000	1.010	1.047
10	16.1	466	237.0	4.6	2.92	279.2	135.9	107.9	163.2	207.9	34.8	76.1	34.0
12	24.3	629	135.7	6.2	2.55	305.4	185.7	120.9	154.5	193.7	26.9	70.6	31.0
Average	20.2	547	186.3	5.4	2.73	292.3	160.8	114.4	158.8	200.8	30.8	73.3	32.5
10 × 12 F_1	29.6	759	111.3	6.9	2.33	328.7	237.9	113.4	194.2	222.4	31.8	70.6	33.9
Ratio	1.465	1.388	0.597	1.278	0.854	1.125	1.480	0.991	1.223	1.108	1.032	0.963	1.043
12	24.3	629	135.7	6.2	2.55	305.4	185.7	120.9	154.5	193.8	29.4	67.5	36.3
1	18.0	449	174.6	5.8	3.16	309.9	154.6	105.8	154.2	193.7	26.9	70.6	31.0
Average	21.1	539	155.1	6.0	2.85	307.6	170.1	113.3	154.3	193.7	28.1	69.0	33.6
12 × 1 F_1	28.3	734	116.8	7.2	2.52	351.9	215.9	119.3	155.2	226.8	30.0	55.8	35.1
Ratio	1.341	1.362	0.753	1.200	0.884	1.144	1.269	1.053	1.006	1.171	1.068	0.809	1.045
Av. of ratios	1.461	1.448	0.661	1.208	0.814	1.155	1.380	1.077	1.101	1.137	1.043	0.923	1.045

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ımary of relative development of F_1 hybrids and their pure line parents.

ıant characters	Counts and measurements			
	Actual		Relative	
	Parents	Hybrid	Parents	Hybrid
(1)	(2)	(3)	(4)	(5)
.....	115	117	100	102
.....	4.3	6.5	100	151
.....	1.7	3.2	100	188
(mm.)	19.8	29.3	100	148
me (cu. mm.)	130,848	439,036	100	335
in.)	704	1,028	100	146
cross section of stalk	519	743	100	143
ıre cm. of stalk	177.8	111.0	100	62
ong 1 diameter of stalk	5.7	6.8	100	119
. of stalk diameter	2.85	2.21	100	77
›undle of stalk (mm.)	.300	.347	100	115
(mm.)	.1126	.1190	100	106
ım.)	.160	.182	100	114
1 pith cell (cu. mm.)	.0016037	.0020230	100	126
.....	.200	.226	100	113
ıidermal cell of leaf (mm.)	.0307	.0321	100	104
f leaf (mm.)	.0337	.0355	100	105
1 cm. of leaf width	69.6	64.7	100	93

n F_1 hybrids, 4x1, 2x10, 12x2, 4x12, 10x5, 12x5, 10x12, and for their pure line parents. The
the average as often as they occur in the hybrids.
mmarized from Tables 14, 16, and 38.

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thickness was 14 per cent greater, (11) the average thickness of the upper and lower epidermal cell was 4 per cent greater, (12) the number of vascular bundles in one centimeter cross section of the leaf was 8 per cent lower, (13) the width of epidermal cells on the upper and lower leaf surface averaged 4 per cent greater. This, in view of a 46 per cent increase in leaf area, suggests a larger increase in cell numbers than in cell size.

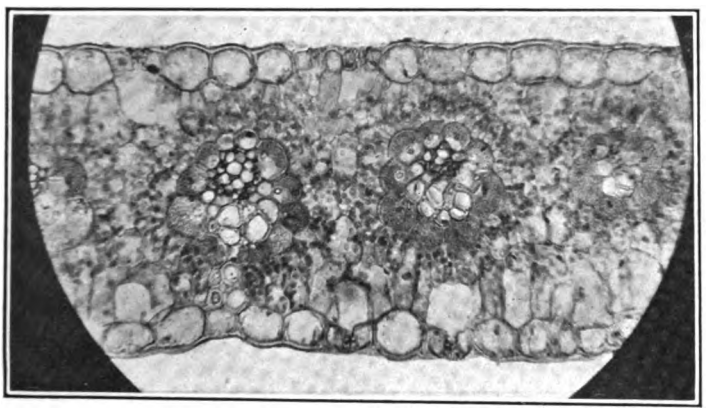

Fig. 23.—Cross section of corn leaf taken midway between midrib and margin. Arrangement of cells and vascular bundles is shown. Some histological leaf measurements for corn hybrids and their inbred parents are given in Tables 38 and 39.

From the above comparisons it may be concluded that crossing of homozygous (pure line) plants is accompanied by a marked increase in both size and number of histological units. The homozygous plants appear to be more sluggish in their physiological activities than are heterozygous (hybrid) plants, since it takes practically the same length of growing period to mature a much smaller number of cells which are also smaller in size.

An interesting point in connection with heterosis, or increase of growth resulting from crossing pure lines, is, how much of this increase is due to increase in cell size and how much to increase in cell numbers.

Most of the cells in a corn plant are so irregular in shape and so irregularly arranged that it is very difficult to determine their relative sizes. Therefore most of the cell measurements were confined to pith cells of the stalk and epidermal cells of the leaves.

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If we assume that other cells differ as much in size on an average as the pith cells do, we may make such comparisons as follow.

The approximate volumes of inbred and hybrid stalks, Table 39, were 130,848 cubic mm. and 439,036 cubic mm., giving a ratio of 100:335. The volumes of average inbred and hybrid pith cells for the same strains and hybrids were .0016037 cubic mm. and .0020230 cubic mm., giving a ratio of 100:126. These data suggest that 10.6 per cent of the increased size due to crossing results from an increase in cell size and 89.4 per cent of it from increased numbers. The cell size increased 26 per cent and the cell number 209 per cent. Cell measurements in other tissues suggest that the average cell size of the plant was not increased to a greater percentage than were the pith cells.

EAR-TO-ROW BREEDING

TESTS WITH HOGUE'S YELLOW DENT CORN

Ear-to-row breeding of corn consists in the separate comparative yield determination of individual ears of a commercial variety with the object of isolating the more productive strains. An ear-to-row strain is the progeny in direct line of descent from an individual ear of corn. A number of plans for continuing the apparently superior strains after once being determined have been compared at the Nebraska Experiment Station. These plans are as follows:

1. Continuous ear-to-row selection in which progressive improvement is attempted annually by ear-to-row selection within the most productive ear-to-row strains. This work has been continued with three of the most productive "Class I" ear-to-row strains selected in 1903 from among 104 ears tested.

In 1907 two separate selections were made from one of these and continued as separate strains. For this reason, strains 425 and 459 as shown in chart 4 were identical during the first three years. The pedigree record of yields which indicates the choice of plats from which seed selections were made for continuing the strains is given in chart 4. In several instances selections were not made from the highest yielding plat, because quality as well as yield was taken into consideration.

Seed for the comparative yield test reported in Table 40 was prepared each year by mixing the well-developed ears of the highest yielding rows of the four strains.

(2) Continuing the strain by increasing the original ear

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CHART 4.—*Tracing the yield pedigree of four Class I ear-to-row strains of Hogue's Yellow Dent corn which have undergone continuous selection during the period of 1903-1916.*

Strain No.	Yield of grain per acre—bushels												
	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916
403	91.5	74.5	99.7	74.3	97.4	....	25.5	54.8	37.4	43.2	13.9	51.4	82.6	30.1
		81.6	89.8	77.1	81.6	....	34.5	65.0	30.3	47.0	14.1	50.6	74.8	35.3
		76.5	88.5	69.0	82.8	....	25.6	57.5	34.9	45.7	6.9	52.4	73.5	42.6
		71.0	.....	....	93.1	....	26.7	56.1	32.3	45.0	15.7	49.2	71.9	26.7
		78.7	.....	....	78.7	....	34.8	....	34.4	45.1	19.6	37.7	86.6	33.8
		81.6	.....	....	87.7	....	26.6	....	35.5	42.8	14.0	54.8	86.6	19.9
	Average....	77.3	92.7	73.5	86.9		28.9	58.3	34.1	44.8	14.0	49.3	79.3	31.4
425	95.0	44.4	76.6	99.1	76.8	....	28.1	49.7	37.7	52.0	13.0	50.9	88.2	36.7
		61.7	118.2	87.3	84.3	....	33.0	52.3	35.8	56.2	17.7	53.4	94.0	24.0
		69.1	99.7	78.9	78.4	....	23.5	47.7	38.5	47.3	13.5	50.8	96.1	33.0
		88.4	.....	....	93.0	....	29.6	52.5	39.3	65.3	19.6	47.7	97.3	22.1
		37.3	.....	....	87.1	....	27.3	49.2	38.9	53.6	13.1	60.8	101.6	31.2
		78.4	.....	....	88.1	....	27.1	48.7	31.6	57.8	15.8	55.0	78.7	23.2
	Average....	63.2	98.2	88.4	84.6		28.1	50.0	37.0	55.4	15.4	53.1	92.6	28.4
459	95.0	44.4	76.6	99.1	99.3	....	30.6	57.9	31.6	49.5	15.1	47.5	96.6	35.7
		61.7	118.2	87.3	90.9	....	39.5	50.3	37.6	48.8	13.1	64.5	92.6	31.0
		69.1	99.7	78.9	83.7	....	37.3	59.5	33.0	44.8	14.9	39.9	93.6	38.1
		88.4	.....	....	91.5	....	34.2	56.9	35.4	42.0	12.0	48.0	94.7	39.0
		37.3	.....	....	83.8	....	33.7	54.2	33.6	50.1	13.8	44.2	96.5	42.5
		78.4	.....	....	89.7	....	31.1	....	36.6	53.9	13.0	50.6	95.1	38.3
	Average....	63.2	98.2	88.4	89.8		34.4	55.8	34.6	48.2	13.6	49.1	94.8	37.4
4182	100.8	73.9	80.9	84.7	90.3	....	29.1	45.7	34.4	59.3	19.2	51.4	70.1	28.0
		62.0	101.1	77.7	87.7	....	28.7	39.4	37.2	53.0	10.9	44.0	86.0	33.4
		80.7	102.0	91.8	81.9	....	23.2	44.4	30.5	60.3	13.4	54.3	82.0	40.9
		60.1	97.7	....	91.9	....	15.5	49.1	27.7	54.6	10.6	49.4	79.3	35.5
		77.8	105.0	....	75.8	....	23.7	48.8	37.6	58.7	8.1	45.4	86.3	41.0
		80.7	88.2	....	90.8	....	22.6	....	39.9	51.4	12.8	41.6	92.3	....
	Average....	72.5	95.8	84.7	86.4		23.8	45.5	34.5	56.2	12.5	47.7	82.7	35.8

The average yields for the four families Nos. 403, 425, 459, and 4182 for all years were respectively 55.87, 57.86, 58.96, and 56.65 bushels per acre, while the corresponding yields of the individual ear-to-row plats selected for continuation each year were 60.48, 67.27, 66.16, and 62.44. This is an average difference of 6.7 bushels in favor of the selected plats.

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remnant of the high yielding ear in an isolation plat and thereafter always growing it isolated from other corn to avoid "contamination." The remnant of a single high yielding ear (No. 64) of the Class II ear-to-row tests made in 1906 and 1907 furnishes the basis for this study. In 1907, strain No. 64 yielded 81.2 bushels per acre as compared with 64.4 bushels for the original Hogue's Yellow Dent. In 1908 the one-third remnant of the original ear was grown isolated from other corn. The seed stock has been continued since by shelling together a large number of the better developed ears and growing in an isolation plat. Similarly selected seed was used in the comparative yield tests reported in Table 40.

(3) Mixing several productive ear-to-row strains and increasing thereafter in a single isolation plat without further selection except the choice of well-developed seed ears. This seed stock originated in four productive "Class II" ear-to-row strains. In the initial tests in 1906 and 1907 these four ears

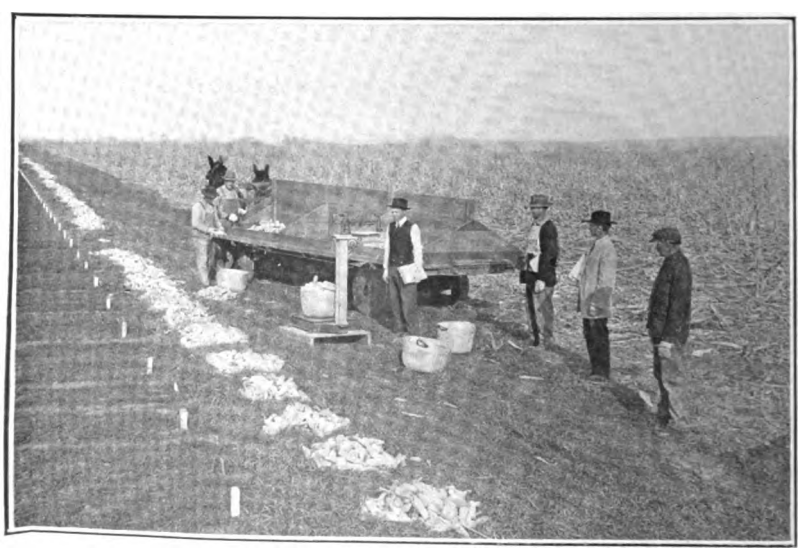

FIG. 24.—Harvesting ear-to-row breeding plats. The corn from the various rows is weighed separately and placed in piles at the end of the field for study of ear type and quality. Special samples are saved for making shrinkage and shelling determinations. The flat-boat has three compartments on each side, and permits husking six rows at each round by three huskers.

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were outstanding in yield, averaging 79.4 bushels per acre in 1907, as compared with 64.4 bushels for the original corn.

A number of well-developed progeny ears grown from each of these four strains were shelled together into one composite sample for planting an isolation increase plat. This composite sample of four strains has ever since been continued in the same manner by merely selecting a large number of well-developed ears to be shelled together in composite. Seed for the comparative yield test reported in Table 40 has been obtained each year in the same manner.

(4) Natural crossing of high yielding ear-to-row strains. Hybridization of ear-to-row strains was commenced in 1909, using as a basis the same four "Class I" strains that have been used in the continuous ear-to-row breeding experiments. The first year, two rows of each strain were planted in the middle of a twelve-row plat of one of the other strains. These two rows were detasseled to supply the hybrid seed. In the following year, and thereafter, the seed stock was continued by intercrossing the four hybrid combinations just as described for the individual strains the first year. The strains had lost their identity after the first few years and future crossing practically amounted to using seed from detasseled rows. The four hybrids have been mixed each year for the yield test reported in Table 40.

RESULTS FROM THE VARIOUS METHODS OF EAR-TO-ROW BREEDING WITH HOGUE'S YELLOW DENT CORN

The comparative yields from the various methods of ear-to-row breeding with Hogue's Yellow Dent corn are given in Table 40 for the seven-year period 1911-1917. All special selections are compared directly with each other and with the original Hogue's Yellow Dent corn, which has been continued by merely selecting well-developed ears for seed each year.

Continuous ear-to-row selection for a period of eight to fourteen years resulted in an average yield of 0.3 bushels per acre less than the original. Continuing a single strain in an isolation plat for a period of four to ten years resulted in an average yield of 5.9 bushels per acre less than the original. Mixing four high yielding ear-to-row strains and growing for a period of two to eight years in an isolation plat without further special selection resulted in an average yield of 1.4 bushels per acre greater than the original. Crossing ear-to-row strains for a period of two to eight years resulted in a yield of 0.9 bushel per acre more than the original.

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)—*Effect of ear-to-row breeding on the yield of corn (Hogue's Yellow Dent corn). Seven years, 1911 to 1917.*

Kind of ear-to-row breeding	Yield per acre							
	1911	1912	1913	1914	1915	1916	1917	Av.
(1)	*Bu.* (2)	*Bu.* (3)	*Bu.* (4)	*Bu.* (5)	*Bu.* (6)	*Bu.* (7)	*Bu.* (8)	*Bu.* (9)
l Hogue's Yellow Dent	42.6	51.6	9.8	62.8	79.5	71.7	57.4	53.6
ious ear-to-row selection since 1903	44.0	52.9	7.7	65.3	76.8	69.8	56.6	53.3
ed from single high yielding strain selected in 1906	38.2	45.6	7.3	55.0	75.3	58.9	53.6	47.7
ed from composite of four strains selected in 1906	42.5	54.6	12.1	63.5	80.0	74.4	57.9	55.0
ssing of four strains selected in 1906	41.6	55.3	9.1	64.7	84.1	69.4	57.3	54.5
replications	4	4	5	3	7	4	4	

row g	Summary of plant characteristics, 4-year average, 1914-1917									
	Stalk height	Ear height	Date tasseling	Date ripe	Lodging	2-eared stalks per 100 plants	Ears per 100 plants	Suckers per 100 plants	Shrinkage of ear corn	Shelling per cent
	Inches (10)	*Inches* (11)	(12)	(13)	*Per cent* (14)	(15)	(16)	(17)	*Per cent* (18)	*Per cent* (19)
.....	92	48	7/29	9/22	22	16	96	28	10.3	84.6
.....	90	47	7/29	9/22	22	16	97	22	8.9	85.0
.....	93	47	7/29	9/22	23	10	94	25	8.5	84.7
.....	93	46	7/28	9/22	20	11	101	38	9.7	84.9
.....	94	47	7/28	9/22	21	15	95	25	8.3	84.9

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The entire range of results from the various ear-to-row breeding methods varies from a reduction in yield of 12.5 per cent to an increase of 2.6 per cent over the original corn. Allowing for a small possible experimental error, we may conclude that the slight improvement in yield indicated for eighteen years of ear-to-row breeding offers little promise in a practical way.

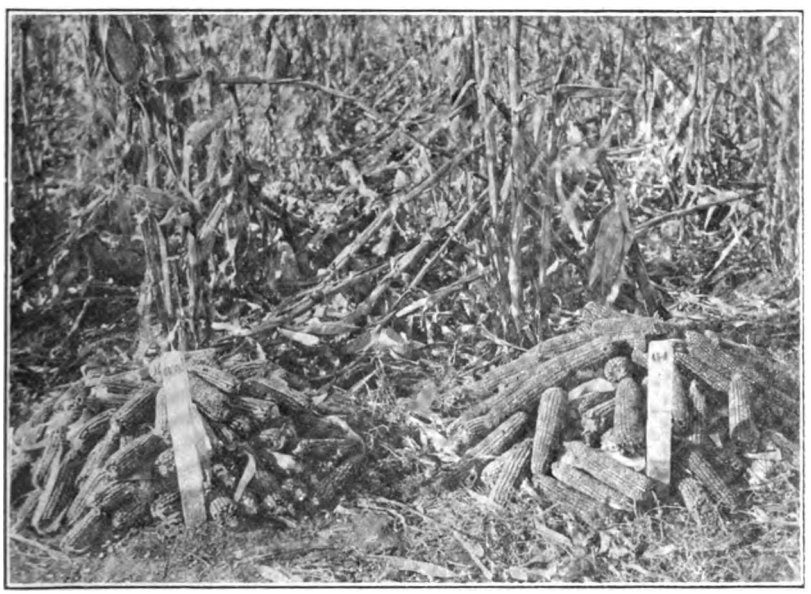

FIG. 25.—Two plats in an initial ear-to-row test in 1907. Row No. 64 yielded 81.2 bushels and row No. 65 yielded 58.7 bushels in comparison with 64.4 bushels for the original Hogue's Yellow Dent. The remnant of ear No. 64 was increased and grown thereafter in an isolation plat. During the seven years, 1911-1917, this seed has produced 5.9 bushels less per acre than the ordinary variety from which it was selected, probably due to close breeding. See Table 40 for method No. 3. (From Nebraska Bulletin 112, figure 2.)

We should bear in mind that this work has been done with a well-adapted variety. Had a poorly acclimated variety been used, doubtless marked improvement might have resulted from continuous ear-to-row breeding thru selection of the better adapted strains.

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EAR-TO-ROW BREEDING OF NEBRASKA WHITE PRIZE CORN

An initial ear-to-row test was made in 1911 with Nebraska White Prize corn. Remnants of these two hundred ears were given a duplicate test in 1912. Remaining remnants of the eight best producing ears were planted in ear-to-row plats in 1913 to be used thereafter in a continuous ear-to-row experiment.

Six well-developed ears were selected from each of these plats and planted in individual ear-to-row plats in 1914. Six ears were in turn selected from the most productive one of the six rows representing each strain, for planting in 1915 and successive years.

In a second experiment a small amount of seed from the remnants of each of the above high yielding ears was mixed in 1913 for planting in an isolation plat. This seed stock has been continued each year in an isolation plat, without further selection aside from the choice of a large number of well-developed ears which were shelled in composite.

In a third experiment the eight strains have been intercrossed each year in the manner described on page 105 for Hogue's Yellow Dent.

For the comparative yield test of corn continued by the various methods of ear-to-row breeding reported in Table 41, seed of the eight strains subjected to any one treatment has been mixed, so that the yields are for the eight strains in composite.

As an average for the five years, compared with the original Nebraska White Prize corn, (1) continuous ear-to-row breeding yielded 0.5 bushel less; (2) isolation increase of eight high yielding strains in composite yielded 3.0 bushels less; (3) intercrossing of eight best strains yielded 1.1 bushels more.

The yields in the initial ear-to-row tests during 1911 and 1912 of the eight strains used in the above tests are given in Table 42. As an average for the two years, these eight strains surpassed the original Nebraska White Prize corn by 12.8 bushels. Much of the earlier enthusiasm for ear-to-row breeding was based upon the indication of superiority in the initial tests of the mother ears before the work had progressed sufficiently far to make more extensive practical field progeny tests.

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of ear-to-row breeding on the yield of corn (Nebraska White Prize corn). Seven years, 1913-1917 and 1920-1921.

›-row breeding	Yield of grain per acre								
	1913	1914	1915	1916	1917	1920	1921	7-year average 1913–1921	5-year average 1915–1921
:)	*Bu.* (2)	*Bu.* (3)	*Bu.* (4)	*Bu.* (5)	*Bu.* (6)	*Bu.* (7)	*Bu.* (8)	*Bushels* (9)	*Bushels* (10)
White Prize	10.0	52.3	75.5	73.8	48.2	52.4	68.6	54.4	63.7
·ow breeding	10.4	50.0	72.2	73.0	46.8	55.7	68.5	53.8	63.2
t strains	12.3	49.0	71.6	72.5	47.7	47.0	64.6	52.1	60.7
ains	.....	.....	73.7	74.1	47.9	59.1	69.4	.....	64.8
ications	3	6	6	4	4	3	3		

Summary of plant characteristics, 5-year average, 1915-1917 and 1920-1921

lk ht	Ear height	Date tasseling	Date ripe	Lodging	2-eared stalks per 100 plants	Ears per 100 plants	Suckers per 100 plants	Shrinkage of ear corn	Shelling per cent
es)	*Inches* (12)	(13)	(14)	*Per cent* (15)	(16)	(17)	(18)	*Per cent* (19)	*Per cent* (20)
1	50	8/3	9/22	28	12	104	18	10.0	82.9
9	51	8/5	9/22	26	11	102	13	15.1	82.8
)	48	8/3	9/22	29	7	95	16	10.7	81.0
	51	8/3	9/23	28	11	99	16	10.8	82.2

in these ear-to-row experiments has its origin in the eight highest yielding strains reported in

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TABLE 42.—*Comparative yields of original corn and eight highest yielding Nebraska White Prize ear-to-row plats out of 200 rows planted during 1911 and 1912.*

Strain No.	Yield per acre		
	1911	1912	Average
	Bushels	*Bushels*	*Bushels*
3	52.0	63.0	57.5
217	48.8	60.2	54.5
69	54.0	54.0	54.0
179	49.0	56.0	52.5
22	48.0	57.0	52.5
5	46.0	58.0	52.0
171	45.8	54.5	50.1
14	41.0	62.0	51.5
Average	48.1	58.1	53.1
Original	35.8	44.9	40.3

These strains furnish the basis for the various lines of ear-to-row work reported in Table 41.

DETASSELING GOOD VERSUS POOR STALKS IN THE SEED PLAT

During the eleven year period 1907-1917, an experiment was conducted to determine whether a profitable increase in production might be had by selecting the seed corn from a seed plat in which the apparently inferior plants had been detasseled to insure against the use of seed which had been fertilized by plants of inferior appearance.

In 1906, two isolation seed plats were planted to Hogue's Yellow Dent corn. In the one plat the poorest one-half of the plants were detasseled and in the other the best one-half of the plants were detasseled. The following year these two lots of seed were continued in separate isolation seed plats by merely shelling together a large number of well-developed ears from each plat. Both plats were again subjected to the same treatment as that of the previous year, and so thruout the entire period of eleven years. Thus there was opportunity for cumulative effect to assert itself.

Each year these two lots of seed were compared with each other and with the original Hogue's Yellow Dent corn in a separate yield test. During the last seven years of the test, a cross between the two lots of seed was also included. The results are given in Table 43.

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As an average for eleven years, the seed fertilized by the best one-half of the plants yielded 0.9 bushel more than the seed fertilized by the poorest one-half of the plants. However, both yielded respectively 1.5 bushels and 2.4 bushels less than the original corn. This slight reduction in yield suggests a possible effect of somewhat narrowing down the fertilization in both cases. An increase in yield over the two lots respectively of 3.7 bushels and 2.4 bushels per acre from a cross between the two during the last seven years tends to substantiate this.

TABLE 43.—*Good versus poor stalks detasseled. Hogue's Yellow Dent corn. 1907-1917.*

Year	No. of replications	Original Hogue's Yellow Dent	Good stalks detasseled	Poor stalks detasseled	F_1 cross of good and poor stalks detasseled
(1)	(2)	(3)	(4)	(5)	(6)
1907	1	63.7	66.1	70.2	.....
1908	1	34.2	34.7	33.9	.....
1909	4	38.6	37.1	32.7	.....
1910	4	55.4	51.7	53.9	.....
1911	4	42.6	39.1	37.6	42.6
1912	4	51.6	48.7	55.6	52.8
1913	5	9.8	5.9	3.8	6.2
1914	3	57.1	55.1	54.2	59.2
1915	7	79.5	69.5	72.7	76.1
1916	4	71.7	70.5	71.1	75.9
1917	4	57.4	57.1	60.1	59.2
Average 11 years	.....	51.1	48.7	49.6	.....
Average 7 years	.....	52.8	49.4	50.7	53.1

It is evident that detasseling the poorest appearing one-half of the plants in a seed plat has not resulted in an increased yield over the original corn produced and selected in the ordinary way. The difficulty of establishing inherent inferiority by mere appearance is probably an obstacle in the way of effective improvement by this method.

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NATURAL COMPETITION AS A FACTOR IN CORN IMPROVEMENT

Competition and survival of the fittest has long been recognized as a principle in the evolution of living organisms. Investigations have been made with two varieties of corn—Hogue's Yellow Dent and Nebraska White Prize—to determine whether this natural principle might be utilized in the improvement of corn. With reference to this principle, corn was planted in three rather large plats at the rates of 1, 3, and 5 plants per hill respectively. Hills were 44 inches apart each way.

In the case of Hogue's Yellow Dent corn, continuous seeding at the three rates has been carried on since 1905, and with the other variety since 1911. Each year from thirty to fifty of the best developed ears produced under the respective planting rates were mixed for continuing the seed the next year. The seed ears were harvested from the standing stalks to be certain that they actually came from plants growing at the specified rates. Typical seed ears of the three groups are shown in figure 26.

In addition to the seed increase plats, other plats have been planted for determining the comparative yields of the various lots. In these yield tests, each of the three lots of Hogue's Yellow Dent have been compared at the three planting rates, viz, 1, 3, and 5 plants per hill. The Nebraska White Prize, on the other hand, has been tested for yield only at the rate of three plants per hill, which is considered normal for this region. The yields per acre are given in Tables 44 and 45.

As an average for the seven years 1911 to 1917, when the Hogue's Yellow Dent was tested at the normal rate of three plants per hill, the seed which had been previously grown at the rate of five plants per hill has yielded 0.6 bushel more while seed previously grown at the rate of one plant per hill has yielded 1.8 bushels less per acre than the seed grown at the customary rate of three plants per hill.

In a similar comparison during eight years with Nebraska White Prize, the seed previously grown at the rate of five plants per hill has yielded 0.2 bushel more while seed from the one rate yielded 0.1 bushel per acre less than the seed grown at the customary rate of three plants per hill.

The results obtained from the Hogue's Yellow Dent "competition" strains when tested at the respective rates of one plant and five plants per hill were rather similar to those obtained

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...—*Effect of previous rate of planting upon the seed value of corn (Hogue's Yellow Dent). Seven years, 1911-1917.*

Summary of plant characteristics for period									Yield of grain per acre							
Stalk height	Ear height	Date ripe	Lodging	2-eared stalks per 100 plants	Ears per 100 plants	Suckers per 100 plants	Shrinkage of ear corn	Shelling per cent	1911	1912	1913	1914	1915	1916	1917	Av.
Inches (2)	*Inches* (3)	(4)	*Per cent* (5)	(6)	(7)	(8)	*Per cent* (9)	*Per cent* (10)	*Bu.* (11)	*Bu.* (12)	*Bu.* (13)	*Bu.* (14)	*Bu.* (15)	*Bu.* (16)	*Bu.* (17)	*Bu.* (18)
YIELD TEST MADE AT RATE OF 1 PLANT PER HILL																
88	45	9/24	10	36	160	93	9.9	82.8	33.1	45.9	8.6	42.3	56.1	33.2	30.7	35.7
88	45	9/24	12	39	169	99	10.7	84.2	33.8	52.0	9.8	41.4	52.6	33.6	27.3	36.3
89	45	9/24	10	42	182	110	10.9	82.7	36.2	49.0	12.1	42.1	64.0	34.2	27.7	37.9
88	45	9/24	11	39	170	101	10.5	83.2	34.4	49.0	10.2	42.9	57.6	33.7	28.6	36.6
									4	4	4	4	4	4	4	
YIELD TEST MADE AT RATE OF 3 PLANTS PER HILL																
88	44	9/23	27	10	80	23	10.4	83.8	49.9	55.5	5.7	44.1	80.5	38.0	49.4	46.8
87	44	9/23	28	11	89	25	9.9	83.6	55.5	40.1	6.4	46.1	80.2	38.2	48.9	45.1
88	44	9/23	24	11	89	28	10.1	83.3	60.5	39.6	7.8	44.3	78.6	36.1	51.8	45.4
88	44	9/23	26	11	86	25	10.1	83.6	55.3	38.4	6.6	44.8	79.8	37.1	50.0	44.6
									4	4	4	4	4	4	4	
YIELD TEST MADE AT RATE OF 5 PLANTS PER HILL																
88	43	9/22	38	7	59	10	10.1	81.5	48.3	24.0	2.3	33.7	83.6	26.7	53.7	38.9
88	43	9/22	38	8	64	9	9.1	82.4	54.8	29.4	4.8	30.3	78.7	30.4	58.8	41.0
87	43	9/22	33	9	65	10	11.7	82.4	58.0	29.2	4.4	32.1	79.4	27.9	56.3	41.0
88	43	9/22	35	8	63	10	10.3	82.1	53.7	27.5	3.8	32.0	80.6	28.3	56.3	40.3
									4	4	4	4	4	4	4	
AVERAGE FOR YIELD TESTS MADE AT THE RATES OF 1, 3, AND 5 PLANTS PER HILL																
88	44	9/23	28	18	100	42	10.1	82.7	43.8	35.1	5.5	40.0	73.4	32.6	44.6	39.3
88	44	9/23	26	19	107	44	9.9	83.4	48.0	40.5	7.0	40.3	70.5	34.1	45.0	40.8
88	44	9/23	22	21	112	49	10.9	82.8	51.6	39.3	8.1	39.5	74.0	32.4	45.3	41.5

ect of previous rate of planting upon the seed value of corn (Nebraska White Prize). Eight years, 1912-1917 and 1920-1921.

planting	Yield per acre								
	1912	1913	1914	1915	1916	1917	1920	1921	Average
	Bushels (2)	*Bushels* (3)	*Bushels* (4)	*Bushels* (5)	*Bushels* (6)	*Bushels* (7)	*Bushels* (8)	*Bushels* (9)	*Bushels* (10)
.....	54.3	8.3	52.4	69.4	34.4	49.5	52.0	66.2	48.3
.....	53.8	7.6	50.9	73.8	38.3	45.9	52.4	64.9	48.4
.....	51.8	8.4	52.1	72.7	33.7	52.0	53.1	65.1	48.6
plications...	8	10	12	12	8	8	6	6	

Summary of plant characteristics, 6-year average, 1914-1917 and 1920-1921

Stalk height	Ear height	Date tasseling	Date ripe	Lodging	2-eared stalks per 100 plants	Ears per 100 plants	Suckers per 100 plants	Shrinkage of ear corn	Shelling per cent
Inches (11)	*Inches* (12)	(13)	(14)	*Per cent* (15)	(16)	(17)	(18)	*Per cent* (19)	*Per cent* (20)
102	49	8/1	9/22	27	6	85	12	5.6	82.0
100	48	8/1	9/22	26	8	89	14	5.4	81.8
101	50	7/31	9/22	26	8	89	14	5.3	81.7

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evious rate of planting upon the seed value of corn (Hogue's Yellow Dent). Seven years, 1911-1917.

mary of plant characteristics for period						Yield of grain per acre							
Lodging	2-eared stalks per 100 plants	Ears per 100 plants	Suckers per 100 plants	Shrinkage of ear corn	Shelling per cent	1911	1912	1913	1914	1915	1916	1917	Av.
Per cent (5)	(6)	(7)	(8)	*Per cent* (9)	*Per cent* (10)	*Bu.* (11)	*Bu.* (12)	*Bu.* (13)	*Bu.* (14)	*Bu.* (15)	*Bu.* (16)	*Bu.* (17)	*Bu.* (18)
YIELD TEST MADE AT RATE OF 1 PLANT PER HILL													
10	36	160	93	9.9	82.8	33.1	45.9	8.6	42.3	56.1	33.2	30.7	35.7
12	39	169	99	10.7	84.2	33.8	52.0	9.8	44.4	52.6	33.6	27.3	36.2
10	42	182	110	10.9	82.7	36.2	49.0	12.1	42.1	64.0	34.2	27.7	37.9
11	39	170	101	10.5	83.2	34.4	49.0	10.2	42.9	57.6	33.7	28.6	36.6
						4	4	4	4	4	4	4	
YIELD TEST MADE AT RATE OF 3 PLANTS PER HILL													
27	10	80	23	10.4	83.8	49.9	35.5	5.7	44.1	80.5	38.0	49.4	43.3
28	11	89	25	9.9	83.6	55.5	40.1	6.4	46.1	80.2	38.2	48.9	45.1
24	11	89	28	10.1	83.3	60.5	39.6	7.8	44.3	78.6	35.1	51.8	45.4
26	11	86	25	10.1	83.6	55.3	38.4	6.6	44.8	79.8	37.1	50.0	44.6
						4	4	4	4	4	4	4	
YIELD TEST MADE AT RATE OF 5 PLANTS PER HILL													
33	7	59	10	10.1	81.5	48.3	24.0	2.3	33.7	83.6	26.7	53.7	38.9
38	8	64	9	9.1	82.4	54.8	29.4	4.8	30.3	78.7	30.4	58.8	41.0
33	9	65	10	11.7	82.4	58.0	29.2	4.4	32.1	79.4	27.9	56.3	41.0
35	8	63	10	10.3	82.1	53.7	27.5	3.8	32.0	80.6	28.3	56.3	40.3
						4	4	4	4	4	4	4	
AGE FOR YIELD TESTS MADE AT THE RATES OF 1, 3, AND 5 PLANTS PER HILL													
23	18	100	42	10.1	82.7	43.8	35.1	5.5	40.0	73.4	32.6	44.6	39.3
26	19	107	44	9.9	83.4	48.0	40.5	7.0	40.3	70.5	34.1	45.0	40.8
22	21	112	49	10.9	82.8	51.6	39.3	8.1	39.5	74.0	32.4	46.3	41.5

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of previous rate of planting upon the seed value of corn (Nebraska White Prize). Eight years, 1912-1917 and 1920-1921.

ting	Yield per acre								
	1912	1913	1914	1915	1916	1917	1920	1921	Average
	Bushels (2)	*Bushels* (3)	*Bushels* (4)	*Bushels* (5)	*Bushels* (6)	*Bushels* (7)	*Bushels* (8)	*Bushels* (9)	*Bushels* (10)
.....	54.3	8.3	52.4	69.4	34.4	49.5	52.0	66.2	48.3
.....	53.8	7.6	50.9	73.8	38.3	45.9	52.4	64.9	48.4
.....	51.8	8.4	52.1	72.7	33.7	52.0	53.1	65.1	48.6
ons...	8	10	12	12	8	8	6	6	

Summary of plant characteristics, 6-year average, 1914-1917 and 1920-1921

t	Ear height	Date tasseling	Date ripe	Lodging	2-eared stalks per 100 plants	Ears per 100 plants	Suckers per 100 plants	Shrinkage of ear corn	Shelling per cent
s	*Inches* (12)	(13)	(14)	*Per cent* (15)	(16)	(17)	(18)	*Per cent* (19)	*Per cent* (20)
	49	8/1	9/22	27	6	85	12	5.6	82.0
	48	8/1	9/22	26	8	89	14	5.4	81.8
	50	7/31	9/22	26	8	89	14	5.3	81.7

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when tested at the rate of three plants per hill as previously indicated.

In view of the rather fluctuating results from year to year, the results in favor of seed from a specially thick planted seed plat are probably too slight to justify much consideration.

SELECTION FOR SPECIFIC PLANT AND EAR CHARACTERS

"HIGH LEAF AREA" AND "LOW LEAF AREA" STRAINS

During the six-year period 1905-1910, two distinct types of Hogue's Yellow Dent corn differing in relative leafiness became fairly well established by continuous ear-to-row selection. The specific character in which a difference was sought for in the two types was the ratio of total leaf area per plant (in square

TABLE 46.—*Plant characteristics of a high leaf area strain and low leaf area strain of Hogue's Yellow Dent corn during 6 years of continuous ear-to-row selection for these respective types. 1905-1910.*

Year	Stalk height	Ear height	Dry matter			Leaf area per plant	Leaf area per gram dry matter
			Stover	Ear	Total		
	Inches	*Inches*	*Grams*	*Grams*	*Grams*	*Sq. in.*	*Sq. in.*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
HIGH LEAF AREA, FAMILY NO. 5113							
1905	.....	.....	375	310	685	1,788	2.61
1906	129	58	216	259	475	1,386	2.92
1907	109	45	205	248	453	1,366	3.01
1908	106	48	255	270	526	1,439	2.74
1909	115	50	261	285	546	1,537	2.82
1910	116	45	232	255	487	1,359	2.80
Average						1,479	2.81
LOW LEAF AREA, FAMILY NO. 5123							
1905	.....	.....	320	480	800	1,069	1.34
1906	123	58	211	305	516	1,111	2.15
1907	107	44	187	279	466	974	2.09
1908	104	40	194	221	415	962	2.32
1909	111	46	225	260	485	1,131	2.33
1910	112	43	213	249	462	1,068	2.31
Average						1,052	2.09

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TABLE 47.—*Comparative yields of high-leaf and low-leaf area corn. Hogue's Yellow Dent. 1911-1917.*

Description	Yield per acre (bushels)							
	1911	1912	1913	1914	1915	1916	1917	Average
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Original Hogue's Yellow Dent	52.7	47.4	7.7	57.1	79.5	71.7	57.4	53.4
High leaf area selection	39.6	49.4	4.6	42.0	72.8	67.5	58.9	47.8
Low leaf area selection	46.7	48.2	8.1	53.7	75.2	72.7	53.0	51.1
F_1 hybrid high × low leaf area	52.6	53.6	9.0	52.0	87.0	69.3	57.5	54.4
Number of replications	4	4	5	3	7	4	4	

Description	Date tasseling	Date ripe	Stalk height	Ear height	Leaf area	Suckers per 100 plants	Barren stalks per 100	2-eared stalks per 100 plants	Lodged stalks per 100 plants	Shrinkage of ear corn	Shelling per cent
			In.	*In.*	*Sq. in.*					*Per cent*	*Per cent*
(1)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
Original Hogue's Yellow Dent	7/28	9/22	91	48	1,195	28	2	19	22	8.8	84.6
High leaf area selection	7/29	9/25	91	49	1,340	31	2	16	23	9.7	83.3
Low leaf area selection	7/25	9/20	91	48	1,034	32	2	13	21	8.1	85.8
F_1 hybrid high × low leaf area	7/28	9/22	90	48	1,171	29	3	16	26	8.3	85.0

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inches) to the total dry matter produced (in grams). The basis of selection on the one hand was a high ratio of leaf area to total plant weight, and on the other hand a low ratio of leaf area to total plant weight. The characteristics of the progeny grown each year are shown in Table 46. In 1911 these two types were planted in isolation plats without further selection aside from the use of well-developed ears for seed. These isolation plats have each year provided the seed for the comparative yield test during the six years 1911-1917 which is reported in Table 47.

While neither strain has surpassed the original corn in yield, the low leaf area strain has outyielded the high leaf area strain 3.3 bushels per acre. The low leaf area strain actually yielded 2.3 bushels less than the original while the F_1 hybrid between the two strains, which was made each year by natural crossing, yielded 3.2 bushels more than the low leaf and 6.5 bushels more than the high leaf area strains. The data as a whole suggest a possible superiority of the low leaf area over the high leaf area strains, but also suggest a reduction in yield, probably due to narrow fertilization resulting from the restricted type selection.

SELECTION FOR PLANT CHARACTERS OF NEBRASKA WHITE PRIZE CORN

In 1914 eight lots of ears in composite were selected from a field of Nebraska White Prize corn, representing (1) three degrees of ear height, viz, high, medium, and low; (2) three degrees of erectness of ear on the stalk, viz, erect, medium drooping, and drooping; and (3) two degrees of lodge resistance, viz, standing stalks versus lodged stalks. These various plant types were tested for yield in adjacent plats during the five years 1915-1917 and 1920-1921. Continuous type selection of the most extreme plants for seed was practiced yearly within these same plats. Thus, the pollination was promiscuous between the types, and the selection was confined primarily to the mother parent.

During the five years (Table 48), selection for high, medium, and low ears yielded respectively 51.6, 53.1, and 53.6 bushels per acre. The plants with low ears yielded two bushels per acre

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were chosen for seed. The drooping ears yielded 2.3 bushels more than the erect, while the medium drooping ear yield was 0.1 bushel less. The original corn surpassed that with drooping ears 0.4 bushel per acre.

Seed selected from standing stalks outyielded seed from lodged stalks by 5.6 bushels per acre, and surpassed the original corn 1.6 bushels per acre.

Since selection from the low ear, drooping ear, and standing stalks yielded most in their respective groups, the data suggest that a very slight increase in yield might be expected from selection for a combination of these characters. This increase might approximate three per cent.

The various lots of seed do not transmit nearly so large a type difference as exists between the selected plants upon which the seed was grown.

RELATION OF EAR TYPE TO YIELD OF GRAIN

During six years, 1914-1917 and 1920-1921, four distinct ear types have been selected annually from the standard Nebraska White Prize variety and compared for yield. Ten or more ears were mixed for the seed of each type. The selection has not been continuous, and results indicate the immediate effect of selecting ear types in bulk. Under the circumstances, the male parentage is entirely uncontrolled and represents a mixture of types. The progeny ears of the several types, therefore, do not and cannot be expected to differ in the same degree as did the seed ears from which they were grown. However, there is usually a very apparent tendency in the direction of the special selection. The characteristics of both the ears planted and the ears harvested as well as the plant characteristics and yields per acre are given in Table 49.

In the six-year comparison with long, slender, smooth ears, the long, large, rough ears averaged 5.0 bushels less per acre, ripened four days later, and had a 4.7 per cent greater shrinkage of ear corn. Short, slender, smooth ears and short, large, rough ears yielded practically alike, and intermediate between the other two types. The long, slender, smooth type of ear surpassed all the others and yielded 0.8 bushel more than the original corn, which is a natural mixture of rough, smooth, and intermediate types. These data do not indicate what difference would have resulted from prolonged continued selection.

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TABLE 48.—*Effect of continued selection for certain plant characters. Nebraska White Prize corn. Five years, 1915-1917 and 1920-1921.*

Plant character selected	Yield of grain per acre					
	1915	1916	1917	1920	1921	Average
(1)	*Bushels* (2)	*Bushels* (3)	*Bushels* (4)	*Bushels* (5)	*Bushels* (6)	*Bushels* (7)
SELECTION FOR EAR HEIGHT						
1 Ears high	66.2	37.8	43.0	54.3	56.8	51.6
2 Ears medium high	59.9	44.6	45.2	54.0	61.8	53.1
3 Ears low	61.7	43.7	49.1	53.7	59.6	53.6
SELECTION FOR ERECTNESS OF EAR						
4 Ears erect	66.1	33.7	47.0	55.5	60.9	52.6
5 Ears medium drooping	66.0	30.0	45.0	56.5	65.1	52.5
6 Ears drooping	67.7	39.5	49.3	54.7	63.4	54.9
SELECTION FOR LODGE RESISTANCE OF STALKS						
7 Stalks up	70.4	45.9	50.0	53.6	64.5	56.9
8 Stalks down	61.5	33.9	46.8	52.1	62.3	51.3
9 Original Nebraska White Prize	67.3	43.0	49.4	53.8	63.0	55.3
Number of replications	4	4	4	3	3	

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TABLE 48 CONCLUDED.—*Effect of continued selection for certain plant characters. Nebraska White Prize corn. Five years, 1915-1917 and 1920-1921.*

Plant character selected for	Summary of plant characteristics for 5-year average									
	Stalk height	Ear height	Date ripe	Ears erect	Lodging	Suckers per 100 plants	2-eared stalks per 100 plants	Ears per 100 plants	Shrinkage of ear corn	Shelling per cent
(1)	*Inches* (8)	*Inches* (9)	(10)	*Per cent* (11)	*Per cent* (12)	(13)	(14)	(15)	*Per cent* (16)	*Per cent* (17)
SELECTION FOR EAR HEIGHT										
1 Ears high	102	54	9/22	.....	27	16	9	87	7.3	81.8
2 Ears med. high	98	47	9/21	.....	24	23	7	93	5.4	82.1
3 Ears low	93	44	9/21	.....	23	18	9	90	5.8	82.4
SELECTION FOR ERECTNESS OF EAR										
4 Ears erect	100	49	9/21	42	23	22	11	90	6.2	82.4
5 Ears med. droop	100	49	9/21	29	25	18	9	87	6.7	81.9
6 Ears drooping	102	49	9/21	21	24	16	9	93	6.6	82.5
SELECTION FOR LODGE RESISTANCE OF STALKS										
7 Stalks up	101	48	9/21	.....	22	17	10	96	5.3	82.9
8 Stalks down	102	50	9/21	.....	29	25	9	87	5.9	83.1
9 Orig. Neb. W. Prize	101	51	9/21	.....	26	17	8	94	6.1	82.7

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TABLE 49.—*Relation of ear type to yield of corn (annual bulk selection of Nebraska White Prize). Six years, 1914-1917 and 1920-1921.*

Type of ear planted	Yield of grain per acre						
	1914	1915	1916	1917	1920	1921	Av.
(1)	*Bu.* (2)	*Bu.* (3)	*Bu.* (4)	*Bu.* (5)	*Bu.* (6)	*Bu.* (7)	*Bu.* (8)
1 Long, large, rough	30.0	65.3	64.4	45.9	55.2	64.0	54.1
2 Short, large, rough	44.4	68.9	65.1	49.9	51.5	63.8	57.3
3 Short, slender, smooth	45.0	72.6	60.1	49.2	50.4	65.5	57.1
4 Long, slender, smooth	48.7	66.4	65.2	54.9	56.0	63.2	59.1
5 Ordinary Nebraska White Prize	48.7	64.8	65.5	53.5	53.7	63.7	58.3
Number of replications	6	8	14	7	3	3	

Type of ear planted	Summary of plant characteristics, 6-year average							
	Stalk height	Ear height	Date tassel-ing	Date ripe	Lodg-ing	Suckers per 100 plants	Ears per 100 plants	Shrink-age of ear corn
(1)	*Inches* (9)	*Inches* (10)	(11)	(12)	*Per cent* (13)	(14)	(15)	*Per cent* (16)
1	100	50	8/2	9/22	29	11	85	9.6
2	100	50	8/1	9/21	25	12	91	8.8
3	99	47	7/30	9/18	28	14	97	4.7
4	101	47	7/30	9/18	28	11	98	4.9
5	100	47	8/1	9/21	27	14	95	5.4

Type of ear planted	Ear measurements, 6-year average					
	Ear length	Ear circum-ference	Number of rows per ear	Ear weight	Kernel length	Kernel width
(1)	*Inches* (17)	*Inches* (18)	(19)	*Pounds* (20)	*Inch* (21)	*Inch* (22)
MEASUREMENTS OF EARS PLANTED						
1	9.9	7.7	21.5	1.05	.56	.32
2	7.4	7.4	20.0	0.80	.56	.33
3	7.2	5.8	15.5	0.51	.45	.33
4	10.0	6.2	15.5	0.79	.46	.33
MEASUREMENTS OF EARS HARVESTED[1]						
1	7.0	6.3	19.1	0.46	.51	.32
2	6.9	6.2	18.6	0.48	.51	.32
3	7.5	5.8	17.1	0.47	.48	.31
4	7.3	5.8	17.0	0.47	.46	.32

[1]In 1921, the percentage of rough, medium, and smooth ears was determined for the progeny of each type of ear planted.

The percentages of rough, medium, and smooth ears harvested from the large rough, small rough, small smooth, long smooth, and original unselected corn planted were respectively: 52, 35, and 13; 50, 33, and 17; 13, 39, and 38; 16, 40, and 44; 30, 38, and 32.

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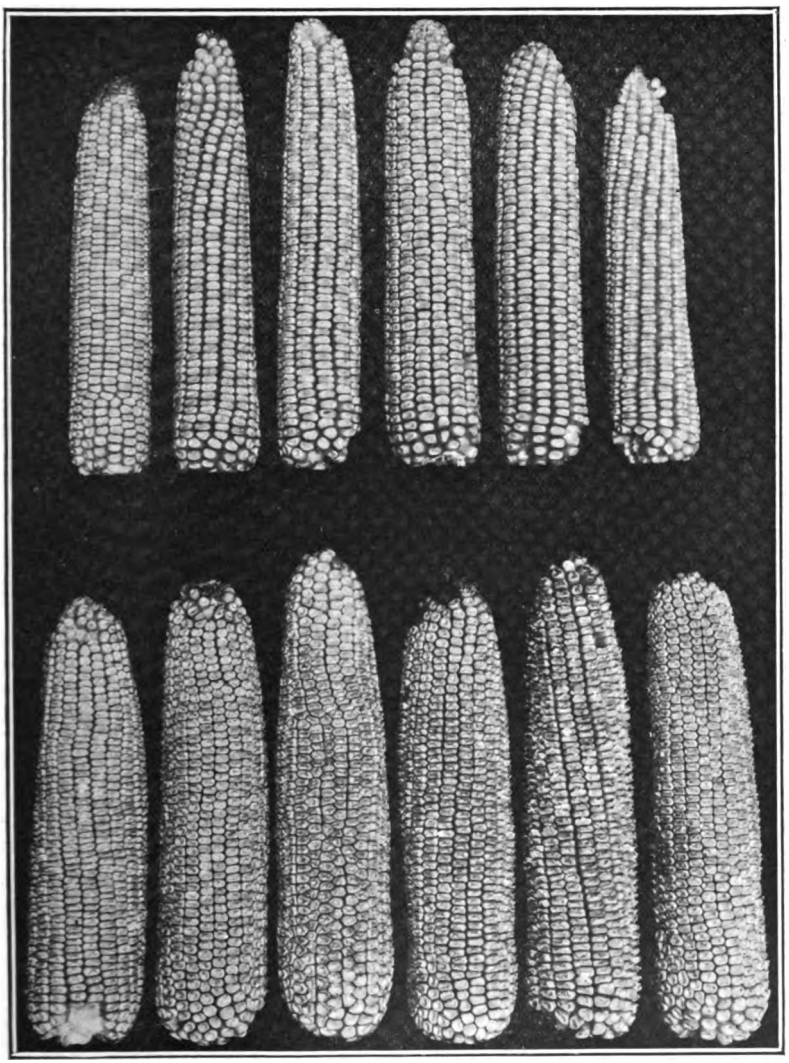

Fig. 27.—Upper row shows long, slender, smooth type of ears and lower row large, rough ears of Nebraska White Prize corn.

Annual bulk selection of the smooth type has surpassed the rough 5.0 bushels per acre during the six years 1914-1917 and 1920-1921.

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During the years 1916 and 1917, deep-grained rough ears and shallow-grained smooth ears were selected in bulk and compared for yield with the original Hogue's Yellow Dent corn. As an average for the two years, the grain yields were respectively 64.0, 69.6, and 64.5 bushels per acre for the three lots. The smooth ears surpassed the original corn 5.1 bushels per acre and the rough corn 5.6 bushels, and showed a tendency for greater earliness. The results are given in Table 50.

TABLE 50.—*Relation of ear type to yield of Hogue's Yellow Dent corn. 1916 and 1917.*

Ear type	Summary of plant characteristics for 2 years						Yield per acre		
	Stalk height	Date tasseling	Date ripe	Ears per 100 plants	Shrinkage of ear corn	Shelling per cent	1916	1917	Average
(1)	*Inches* (2)	(3)	(4)	(5)	*Per cent* (6)	*Per cent* (7)	*Bu.* (8)	*Bu.* (9)	*Bu.* (10)
Deep, rough kernel	87	8/3	9/26	99	8.0	85.5	72.0	56.0	64.0
Shallow, smooth kernel	87	8/1	9/24	112	7.4	84.8	80.1	59.2	69.6
Original	88	8/4	9/25	101	8.5	85.0	71.7	57.4	64.5
Number of replications							4	4	

Further data from this Station, reported in part by Montgomery in 1909 in Bulletin 112, regarding the relation of ear type and yield are given in Table 51. During the six years 1905-1910, long, smooth ears of Reid's Yellow Dent were con-

TABLE 51.—*Long smooth compared with standard medium rough type of Reid's Yellow Dent. 1905-1910.*[1]

Ear type	Yield of grain per acre						
	1905	1906	1907	1908	1909	1910	Av.
(1)	*Bu.* (2)	*Bu.* (3)	*Bu.* (4)	*Bu.* (5)	*Bu.* (6)	*Bu.* (7)	*Bu.* (8)
Long, smooth type	69.7	47.2	69.9	56.8	37.9	62.6	57.3
Standard medium rough type	59.4	51.4	64.1	51.2	35.6	58.4	53.3
Number of plats grown	1	1	1	1	4	4	

[1]Data for the first four years taken from Nebraska Agricultural Experiment Station Bulletin No. 112, by Montgomery.

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trasted for yield with standard medium rough ears of the same variety. The smooth surpassed the rough type 4.0 bushels per acre. This was a test of continuous selection in which seed for the smooth type was repeatedly selected from the smooth type of the preceding year.

In all three of the preceding experiments, covering a total of twelve different years, the long, smooth type of ear surpassed all other types. There are seasonal fluctuations in which the rough equals or surpasses the smoother corn, probably owing largely to climatic conditions favoring the plant type which the rougher ears represent. Since we can not foresee the sort of weather which the season will bring forth, it would seem advantageous to select a somewhat longer, smoother, and shallower grained ear type wherever the corn being grown is a full-season, late-maturing crop. This general conclusion has been reached at least in Ohio, Illinois, and Kansas in addition to Nebraska. Experiments in these four states and in Minnesota and New York have indicated that ear type considerations aside from maturity, soundness, and adaptability are rather neutral in their relation to yield.

The relation of kernel depth to moisture content and freezing injury in a year of late maturity in the fall was shown forcefully in a field of Hogue's Yellow Dent corn at the Experiment Station in 1917. The ears harvested from this field on December 29 were divided into five groups according to their apparent soundness, maturity, and solidity. The moisture content, germination, and kernel length were determined for the grain in each group. Beginning with the most solid and mature group, the germinations, after curing, for the five groups were respectively 93, 59, 14, 5, and 0 per cent. The moisture contents at time of husking, December 29, were respectively 15, 16, 19, 21, and 28 per cent, while the average kernel lengths were 0.49, 0.50, 0.52, 0.54, and 0.57 inches. The deep kernels, representing later maturing plants, contained more water at the time of freezing weather, and for this reason were more subject to freezing injury. Extensive data regarding the correlation between moisture content and susceptibility to freezing injury have been reported in Agricultural Experiment Station Research Bulletin No. 16.

There has been considerable controversy in the past fifteen years regarding the relation of ear type to yield of corn. In lieu of actual experimental evidence, a sudden public interest was gratified for a time in the early nineties by comparing vari-

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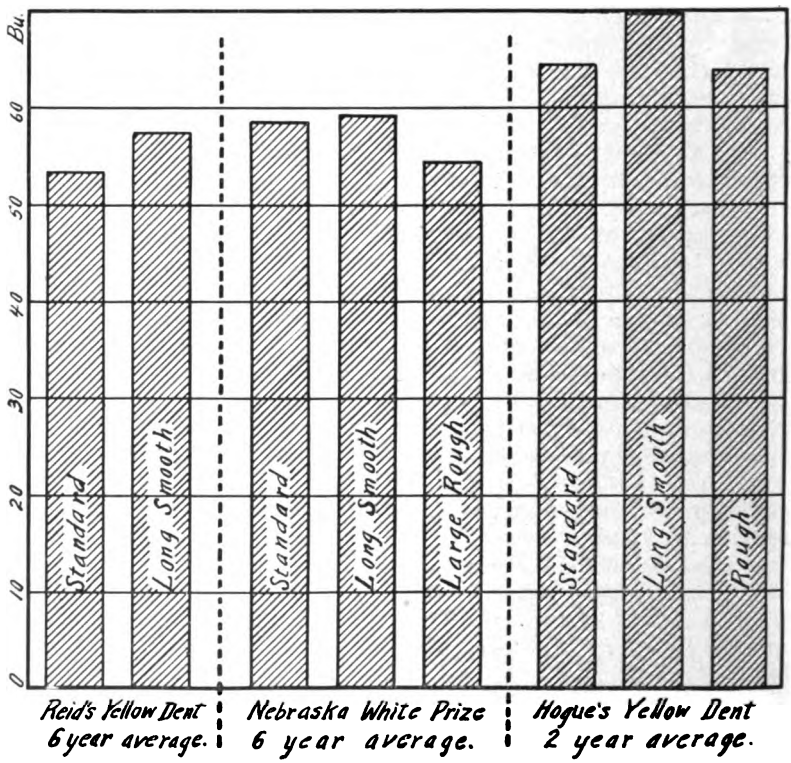

CHART 5.—Relation of ear type to yield. The standard type represents the ordinary unselected seed of the variety tested. Data taken from Tables 49, 50, and 51.

ous ear characteristics with the quantity of grain on an ear. Without further consideration, the amount of grain per ear and

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general vegetative character of a corn variety thru ear type selection. Within a variety, roughness, large ear circumference, many rows on the ear, deep kernels, and high shelling percentage indicate late maturity, large stalk, and relatively large leaf area. These plant characters are concerned in the balance between plant requirement and environment. Thus, it is not the ear character which is the vital consideration in yield, but rather the plant character which is reflected in the ear.

A sharp distinction must be made between ear type selection as herein spoken of and ear type selection for conformity with arbitrary competitive score card specifications. The ear type selections herein spoken of refer essentially to certain plant type corollaries, without any reference to the ear's possible rating for perfection and symmetry of development according to corn show standards. Extensive data from the Nebraska Experiment Station and other institutions and individuals, bearing evidence of the inconsequential nature of many ear characteristics which have been stressed in competitive exhibitions, have been summarized by the writer and accepted for publication in the January, 1922, issue of the Journal of the American Society of Agronomy.

COMPARATIVE YIELDS OF SEED FROM DIFFERENT PARTS OF THE EAR

Corn growers have always been interested in the relative yields to be expected from seed produced on different parts of the ear. During six years, comparative tests have been made of seed taken respectively from the butt, tip, and middle sections of the ear. The results given in Table 52 show no material differences in the respective crops in any regard. The respective yields for butts, tips, and middles were 59.3, 60.4, and 60.2 bushels per acre. Altho the kernels at the tip of an ear are relatively small and their early seedling development is slightly backward, they still contain sufficient food material to support

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TABLE 52.—*Yield of grain from different portions of the ear. Nebraska White Prize corn. Six years, 1914-1917 and 1920-1921.*

Portion of ear used for seed	Yield of grain per acre						
	1914	1915	1916	1917	1920	1921	Av.
(1)	*Bu.* (2)	*Bu.* (3)	*Bu.* (4)	*Bu.* (5)	*Bu.* (6)	*Bu.* (7)	*Bu.* (8)
1 Butt	48.8	77.0	65.0	49.6	52.3	62.8	59.3
2 Tip	49.6	75.3	69.3	52.7	52.8	62.8	60.4
3 Middle	48.0	76.8	68.8	49.4	54.8	63.7	60.2
Number of replications	3	7	7	7	3	3	

Seed from	Summary of plant characteristics during period							
	Stalk height	Ear height	Date ripe	Lodging	Ears per 100 plants	Suckers per 100 plants	Shrinkage of ear corn	Shelling per cent
(1)	*Inches* (9)	*Inches* (10)	(11)	*Per cent* (12)	(13)	(14)	*Per cent* (15)	*Per cent* (16)
1	104	49	9/22	29	93	9	7.5	82.5
2	103	49	9/22	31	95	10	8.3	83.2
3	104	49	9/22	31	96	10	7.2	83.3

RELATION OF SEED MATURITY TO YIELD OF GRAIN

In years of late maturity, the question of special field selection of slightly immature seed corn to escape frost injury commonly arises. A two-year test reported in Table 53 indicates that carefully cured corn selected midway between silking and maturity may possess both high germinative and yielding ability. Corn selected at five weekly intervals before ripe yielded in no case more than two per cent less than fully matured seed. Even tho viability and yield may not be impaired by immature selection, thoro field curing of seed should be practiced as far as possible, since difficulty of curing and preservation are thereby greatly reduced. The above test does not include the effect of unfavorable growth conditions in some seasons. It is possible that small, immaturely harvested seeds would be handicapped under unfavorable climatic or seed bed conditions.

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TABLE 53.—*Relation of maturity of seed to yield per acre. Hogue's Yellow Dent corn, 1916 and 1917.*

Date of seed harvest	Condition of grain	Days since fertilization[1]	Weight of 100 kernels	Ratio weight of embryo to weight of kernel[2]	Germination	Yield per acre		
						1916	1917	Av'ge
(1)	(2)	(3)	*Grams* (4)	(5)	*Per cent* (6)	*Bu.* (7)	*Bu.* (8)	*Bu.* (9)
Sept. 1	Late milk stage	25	17.5	.105	94	78.2	53.6	63.4
Sept. 8	Roasting ear	32	21.1	.110	96	76.9	51.1	64.0
Sept. 15	Late roasting ear	39	24.8	.108	97	73.2	52.8	63.0
Sept. 22	Denting	46	28.4	.106	97	76.2	53.8	65.0
Sept. 29	Glazing	53	31.1	.112	97	72.5	55.5	64.0
Oct. 6	Mature	60	31.6	.....	98	74.3	54.7	64.5
Number of replications						2	2	

[1]Pollination occurred on July 31 and August 10 in 1916 and 1917, respectively.
[2]Data for 1917 only.

EFFECT OF TIME OF SELECTION AND PRESERVATION OF SEED CORN UPON YIELD

This test has previously been reported in Nebraska Agricultural Experiment Station Bulletin No. 163. The object was to determine the effect of the time of harvesting seed corn upon its yielding ability provided care is taken in selection to obtain equally high germination. Comparative yield tests were made in 1915, 1916, and 1917 of September, November, and March field selections made from Nebraska White Prize corn grown at the Experiment Station. The seed was carefully preserved in a dry, well-ventilated place upon being harvested. Only those

TABLE 54.—*Relative yields from seed corn selected at various dates during the fall and winter. 1915-1917.*

Date of seed selection	Duplications each year	Yield per acre			
		1915	1916	1917	Three-year average
(1)	(2)	*Bu.* (3)	*Bu.* (4)	*Bu.* (5)	*Bushels* (6)
September	4	66.6	36.1	38.3	47.0
November	4	65.9	37.3	41.6	48.3
March	4	64.7	42.1	42.6	49.8
Check	4	66.3	40.3	41.1	49.2

1. The seed was harvested about the 15th of each month.
2. The check seed was harvested from the same field while husking in November.

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seed ears were selected which showed a bright, clear germ and thereby promised good germination. A large number of ears were mixed for each selection.

The results given in Table 54 indicate that corn which has been left standing in the field during the cold of winter may yield quite as well as specially fall selected seed, provided its germinative power has not been impaired.

Prudence, however, suggests provision for the next year's seed supply in the fall before the time of possible frost injury. Such early provision greatly reduces the anxiety and extra labor which accompany the selection from among frost injured ears. Frost injury and moisture content of the grain have been shown in Nebraska Research Bulletin No. 16 to be closely correlated. Therefore the time and manner of seed corn preservation may safely be made to vary in different seasons according to prevailing conditions.

SELECTION OF SEED EARS FOR FREEDOM FROM ROOT-ROT DISEASES

Root-rot diseases of corn and their control have been so stressed recently by a number of investigators that it seemed desirable to procure some information based on local experiments. In March, 1921, 959 ears of Hogue's Yellow Dent corn and 497 ears of Nebraska White Prize corn were tested for the presence of root-rot diseases by the accredited germinator test described by Holbert and Hoffer in United States Department of Agriculture Farmers' Bulletin No. 1176. Methods for testing and identification described by these authors were duplicated as nearly as possible. Acknowledgment is extended Dr. G. L. Peltier and Professor R. W. Goss, plant pathologists of the Nebraska Experiment Station, for assistance in identifying the disease and reading the germinator tests. The corn used in these tests consisted of seed ears selected in the ordinary manner from Experiment Station fields used for continuing the ordinary "check" seed of these two varieties. Neither variety had ever been subjected to close selection for type or specialized breeding.

IDENTIFICATION OF ROOT-ROT DISEASES BY THE GERMINATOR TEST

The manner of testing is illustrated in figure 28 and figure 29. The rag doll consists of a sterilized muslin cloth, 12×54 inches, laid upon a sheet of water fibre paper of equal width and six inches greater length. The ten kernels removed spirally from each ear were laid germ down across the cloth in rows two

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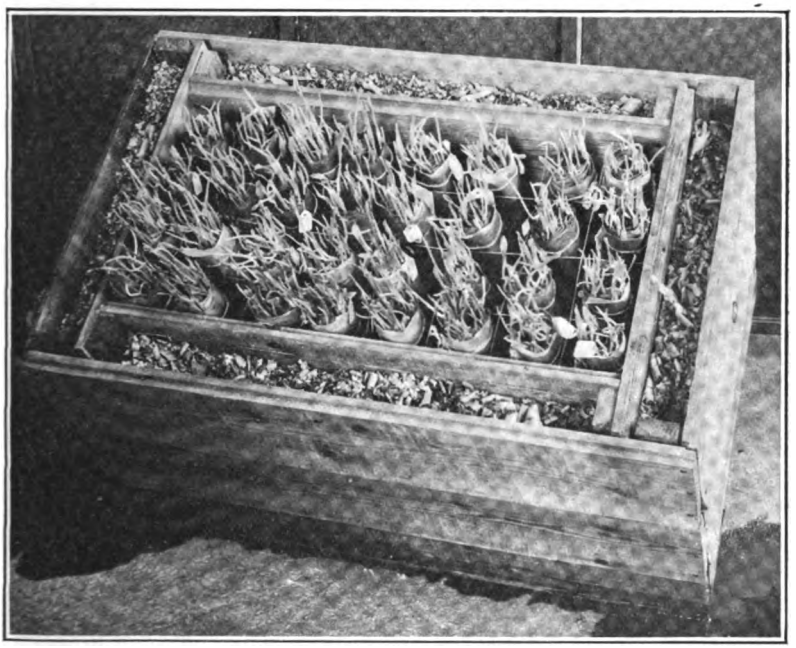

FIG. 28.—Rag doll germinator test for root-rot diseases of individual seed ears employed in these tests. Each doll tests twenty ears, making 640 ears per box. Four such boxes were run in one battery. The inside box is surrounded by three inches of moist sawdust on the sides and below. It has drainage holes at the bottom for draining off free moisture at time of sprinkling the rag dolls. This is a duplicate of the method recommended by Hoffer and Holbert.

inches apart. The kernels all pointed toward one edge of the cloth so that the rolled up rag doll might be placed vertically in the germinator box with the assurance that the root and stem sprouts would point directly down and up respectively. This arrangement facilitated reading the tests and reduced the likelihood of row to row contamination of the sprouting kernels.

The box was kept in a heated room at a temperature ranging from 78° to 85° F. The rag dolls were placed in the box in a thoroly moistened condition and sprinkled daily thereafter. The tests were read at the end of seven days. The sprouted kernels for each ear were classified into four groups, viz, (1) "disease free," which included all sprouted kernels showing no indication

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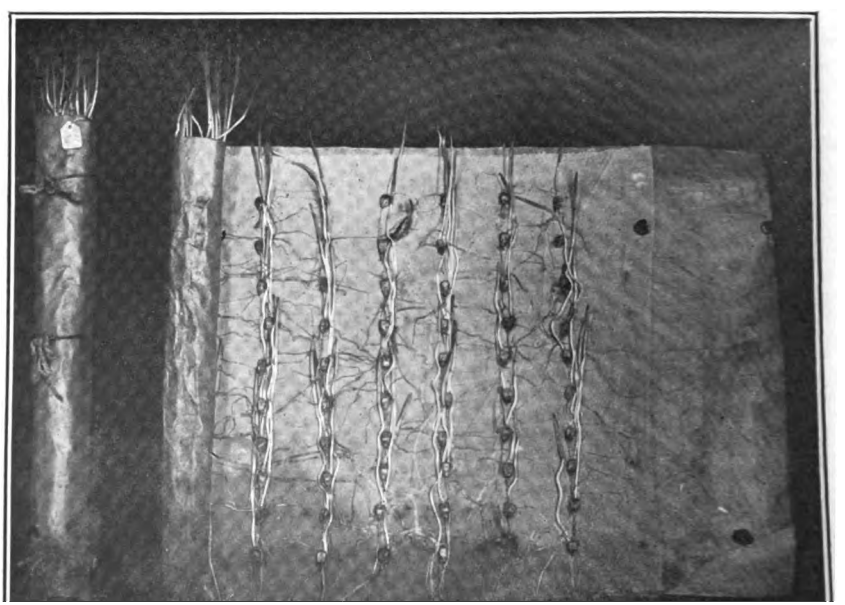
of disease or rotting; (2) "diseased but not rotting," which included all sprouted kernels free from rotting but with apparently characteristic mycelium of *Fusaria* spp. present; (3) "diseased and rotting," which included all sprouted kernels that showed rotting and otherwise corresponded to those of group 2; (4) "dead kernels," which failed to germinate.

The results of the germination test are summarized for each variety in Table 55. As an average of the two varieties, 54.6 per cent of the sprouted kernels were disease free, 29.3 per cent were diseased but showed no rotting, 14.5 per cent were both diseased and rotting, 1.45 per cent were dead. Of the 1,456 ears



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tested, 11.4 per cent were entirely disease free and 88.6 per cent showed more or less disease present, while 10.3 per cent of all were classified as very badly diseased.

In an identification test of root-rot diseases made by T. F. Manns and J. F. Adams, pathologists of the Delaware Experiment Station, the unselected Nebraska White Prize corn used in these tests was found to be 20 per cent infected with *Cephalosporium sacchari*, 20 per cent infected with *Fusarium moniliforme*, and 20 per cent with *Diplodia zeae*. As an average for seed of the 1920 crop from fourteen different sources in Nebraska, 44 per cent of infection with rot diseases was found.

RELATION BETWEEN EAR TYPE AND PRESENCE OF ROOT-ROT DISEASES AS INDICATED BY THE GERMINATOR TEST

Descriptive notes were taken individually of all 1,456 ears tested, regarding the following characters: (1) Ear length, (2) ear diameter, (3) ear weight, (4) roughness, (5) starchiness, (6) luster of germ, (7) moldiness, (8) kernel discoloration, (9) color of shank, and (10) soundness of shank.

Those physical ear and kernel characters of Hogue's Yellow

TABLE 55.—*Results of germinator test to determine amount of root-rot disease present in two standard varieties of dent corn grown at the Nebraska Experiment Station (Hogue's Yellow Dent and Nebraska White Prize). 1921.*

Classification of ears and kernels	Variety tested		
	Hogue's Yellow Dent	Nebraska White Prize	Average
Number of ears tested	959	497	.....
Total number of kernels tested	9,590	4,970	.....
Disease free kernels (per cent)	57.9	51.4	54.65
Kernels diseased but not rotted (per cent)	23.8	34.9	29.35
Kernels diseased and rotted (per cent)	16.8	12.3	14.55
Kernels dead (per cent)	1.5	1.4	1.45
Germination (per cent)	98.5	98.6	98.55
Ears disease free (per cent)	14.4	8.5	11.45
Ears diseased (per cent)	85.6	91.5	88.55
Ears badly diseased (per cent)[1]	10.6	10.0	10.30

[1] "Ears badly diseased" refers in the case of Hogue's Yellow Dent to ears of which five or more of the ten kernels tested showed disease accompanied by rotting. In case of the Nebraska White Prize, a number of ears were included which showed somewhat less rotting, but in such cases not less than eight of the ten kernels indicated disease.

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Dent corn which might possibly be related to the susceptibility to or presence of disease are correlated in Table 56 with the disease readings obtained in the germinator test. Since the ear type and disease readings were made entirely independently of each other, and the ears were arranged in order by random selection, we may assume that the likelihood of systematic errors was eliminated.

Classified according to roughness, the rough, medium, and smooth ears had respectively 49, 55, and 63 per cent of their kernels disease free, while 23, 19, and 12 per cent of the kernels respectively were diseased and rotting. Of the rough, medium, and smooth ears, 8, 13, and 19 per cent respectively were disease free, while 14, 8, and 4 per cent respectively had all of their kernels diseased. Some correlation between degree of roughness and disease is apparent.

Classified according to color of shank, ears with yellow, pink, brown, and normal colored shanks had respectively 75, 66, 49, and 61 per cent disease free kernels, while 14, 10, 24, and 15 per cent of the kernels were respectively diseased and rotting.

Of the ears with yellow, pink, brown, and normal colored shanks, 28, 18, 8, and 18 per cent respectively had no diseased kernels, while 0, 3, 9, and 7 per cent respectively had all of their kernels diseased. Brown shank discoloration appears to be somewhat indicative of disease. The pinkish and yellowish shank colorations noted in these tests were not indicative of disease.

Classified according to soundness of shank, ears with sound, split, and shredded shanks had respectively 57, 60, and 60 per cent of their kernels disease free, while 17, 16, and 17 per cent of the kernels respectively were diseased and rotting.

Of the ears with sound, split, and shredded shanks, 14, 17, and 4 per cent respectively had no diseased kernels, while 8, 8, and 2 per cent respectively had all kernels diseased.

A lower per cent of ears with shredded shanks appear to be entirely disease free than in the case of split or sound shanks.

Classified according to lustre of germ, ears having bright

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ation between ear and kernel characteristics and the presence of root-rot disease as by the germinator test. (959 ears of Hogue's Yellow Dent corn, 1920 crop.) 1921.

er rs as	Number of kernels tested in class	Presence of disease: Number of kernels: Disease free	Diseased but not rotting	Diseased and rotting	Dead	Per cent of kernels: Disease free	Diseased but not rotting	Diseased and rotting	Dead	No. of ears with: All kernels disease free	All kernels diseased	Per cent of ears with: All kernels disease free	All kernels diseased
	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
						EARS CLASSIFIED ACCORDING TO ROUGHNESS							
	1,450	719	361	336	34	49.6	24.9	23.2	2.3	11	20	7.6	13.8
	4,220	2,341	1,038	786	55	55.5	24.6	18.6	1.3	54	35	12.8	8.3
	3,920	2,487	890	491	52	63.4	22.7	12.5	1.3	73	16	18.6	4.1
						EARS CLASSIFIED ACCORDING TO COLOR OF SHANK							
	4,690	2,855	1,057	720	58	60.9	22.5	15.4	1.2	85	35	18.1	7.5
	3,770	1,849	947	907	67	49.0	25.1	24.1	1.8	31	33	8.2	8.8
	950	623	211	100	16	65.6	22.2	10.5	1.7	17	3	17.9	3.2
	180	135	17	26	2	75.0	9.4	14.4	1.1	5	0	27.8	0.0
						EARS CLASSIFIED ACCORDING TO SOUNDNESS OF SHANK							
	6,860	3,908	1,671	1,164	117	57.0	24.4	17.0	1.7	97	52	14.1	7.6
	2,280	1,362	535	359	24	59.7	23.5	15.7	1.1	39	18	17.1	7.9
	450	271	100	75	4	60.2	22.2	16.7	0.9	2	1	4.4	2.2
						EARS CLASSIFIED ACCORDING TO LUSTER OF GERM							
	5,410	3,113	1,340	900	57	57.5	24.7	16.6	1.1	86	44	15.7	8.1
	3,680	2,168	833	611	68	58.9	22.6	16.6	1.9	46	19	12.5	5.2
	500	247	133	94	26	49.4	26.6	18.8	5.2	6	8	12.0	16.0
						EARS CLASSIFIED ACCORDING TO STARCHINESS OF KERNEL							
	880	456	211	193	20	51.8	24.0	21.9	2.3	8	18	9.1	14.8
	3,280	1,898	803	524	55	57.9	24.5	16.0	1.7	44	23	13.4	7.0
	5,430	3,232	1,258	871	69	59.5	23.2	16.0	1.3	76	25	14.0	4.6
						EARS CLASSIFIED ACCORDING TO DEPTH OF KERNEL							
	3,200	1,686	855	605	54	52.7	26.7	18.9	1.7	32	34	10.0	10.6
	5,860	3,536	1,330	906	88	60.3	22.7	15.5	1.5	98	34	16.7	5.8
	530	309	118	100	3	58.3	22.3	18.9	0.6	8	3	15.1	5.7
						EARS CLASSIFIED ACCORDING TO DIAMETER OF EAR							
	3,230	1,721	804	646	59	53.3	24.9	20.0	1.8	40	34	12.4	10.5
	5,840	3,470	1,401	895	74	59.4	24.0	15.3	1.3	89	36	15.2	6.2
	520	331	119	62	8	63.7	22.9	11.9	1.5	9	1	17.3	1.9

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medium starchy, and starchy grain had respectively 59, 58, and 52 per cent disease-free kernels, while 16, 16, and 22 per cent of their kernels respectively were diseased and rotting.

Of the ears with horny, medium, and starchy grain, 14, 13, and 9 per cent respectively had no diseased kernels, while 5, 7, and 15 per cent respectively had all kernels diseased. A slight correlation between starchiness and disease indication is apparent.

Classified according to depth of kernel, ears with shallow, medium, and deep grain had respectively 58, 60, and 53 per cent disease free kernels, while 19, 15, and 19 per cent of their kernels respectively were diseased and rotting.

Of the ears having shallow, medium, and deep grain, 15, 17, and 10 per cent respectively had no diseased kernels, while 6, 6, and 11 per cent respectively had all kernels diseased. Ears with deep kernels appear to be relatively most subject to disease.

Classified according to ear diameter, ears with large, medium, and small diameter had respectively 53, 59, and 64 per cent of their kernels disease free, while 20, 15, and 12 per cent of their kernels respectively were diseased and rotting.

Of the ears with large, medium, and small diameters, 12, 15, and 17 per cent respectively had no diseased grain, while 10, 6, and 2 per cent respectively had all their kernels diseased. Large ear circumference appears to be somewhat correlated with the disease indication of the germinator test.

While there appears to be no reliable correlation between any of the ear characters and the presence of root-rot disease, it seems that the selection of smooth, slender ears having a sound natural colored shank and bright vitreous kernels of only medium depth will materially reduce its presence.

RELATIVE YIELD PERFORMANCE OF DISEASED AND DISEASE FREE CORN AS DETERMINED BY THE GERMINATOR TEST

In 1921, yield tests were made of the comparative performance in the field of badly diseased and disease free ears of Hogue's Yellow Dent and Nebraska White Prize corn as determined by the preceding germinator tests. Seventy disease free Hogue's Yellow Dent ears were compared with the 59 most diseased ears of the same variety in duplicate ear-to-row plats 44 hills in length. Duplicate 4-row plats were also planted

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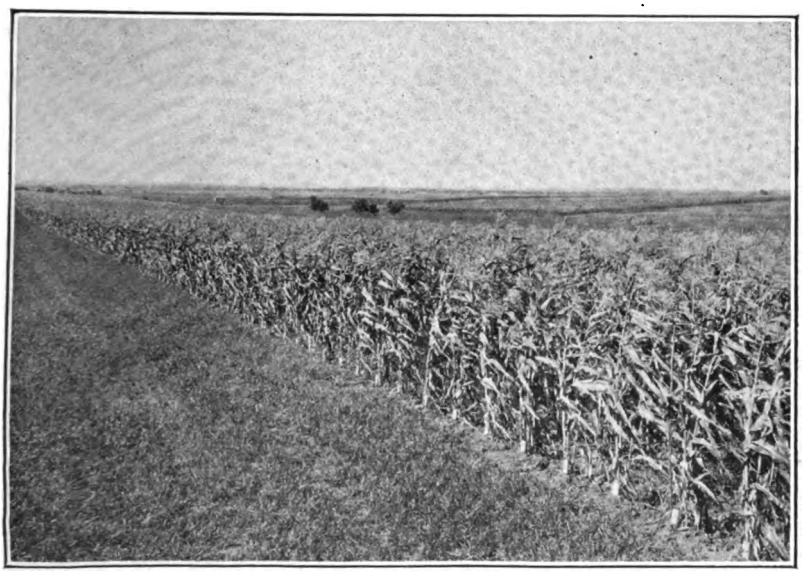

FIG. 30.—The field in which 475 plats were devoted to a study of root-rot diseases in relation to yield in 1921. (See Table 57.)

In these experiments it was thought that failure to produce a plant due to disease should be charged up against the affected seed. The corn was, therefore, planted definitely at the standard rate of three kernels per hill and the yield determined for the entire plat, rather than to plant thick and reduce to a perfect stand. Only ears were used which showed 100 per cent germination in the viability tests. This reduced the complication resulting from lack of vitality due to other causes than disease.

Extensive detailed notes were taken on each field plat regarding stand and growth characteristics which might prove of interest in interpreting results. These are summarized in Tables 57 and 58, to which the reader is referred for comparisons. It

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TABLE 57.—*Field performance of disease free versus diseased corn as indicated by germinator test. (Two varieties and two methods of comparison.) 1921.*

	Duplicate ear-to-row plats						Duplicate 4-row plats with composite seed					
	Hogue's Yellow Dent			Nebraska White Prize			Hogue's Yellow Dent			Nebraska White Prize		
	Disease free	Diseased	Original	Disease free	Diseased	Original	Disease free	Diseased	Original	Disease free	Diseased	Original
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
No. of plats averaged	140	118	30	78	78	19	2	2	2	2	2	2
No. of seeds planted per plat	132	132	132	132	132	132	528	528	528	528	528	528
Stand 21 days after planting (per cent)	87.4	85.4	87.1	86.8	86.3	86.1	83.3	88.0	83.9	85.0	84.0	83.7
Weak plants 21 days after planting (per cent)	2.3	3.1	3.0	1.8	2.3	2.4	3.2	3.2	1.8	3.0	3.2	2.8
No. of plants per plat in fall (actual)	111.6	110.2	112.0	107.3	108.2	107.8	434.5	449.5	433.0	425.5	439.5	432.5
Per cent stand in fall	84.5	83.4	84.9	81.3	82.0	81.7	82.3	85.1	82.0	80.6	83.2	81.9
Date tasseling	7/16	7/16	7/16	7/23	7/22	7/23	7/17	7/17	7/17	7/22	7/22	7/22
Date ripe	9/1	9/1	9/1	9/4	9/4	9/4	9/2	9/2	9/2	9/5	9/5	9/5
Height of plants (inches)	104	104	104	111	109	110	103	102	102	112	109	111
Suckers per 100 plants	11.2	12.9	13.3	4.4	5.3	4.3	8.6	8.4	8.5	8.5	8.2	8.7
Barren plants per 100	6.5	7.8	7.5	9.9	8.6	11.3	5.2	5.2	7.5	8.6	7.5	5.1
Lodged plants per 100	85.2	82.3	83.3	84.6	84.9	84.5	84.0	83.3	84.8	82.7	82.9	81.3
Ears per 100 plants	96.4	95.1	95.0	91.0	91.6	91.8	92.1	94.0	91.0	91.9	86.8	91.7
Shelling per cent	85.0	85.1	84.9	82.1	82.4	82.0	.....	.....	.....	.....	.....	.....
Shrinkage of ear corn (per cent)	0.45	0.30	0.61	1.72	1.95	1.24	.....	.....	.....	.....	.....	.....
Yield per acre (bushels)	58.22	57.53	57.44	44.20	46.54	45.14	51.39	53.45	50.18	46.87	44.79	46.23

The average yields for both varieties, averaged for both types of plats, were as follows: (1) Disease free, 50.2 bushels; (2) badly diseased, 50.6 bushels; (3) original, 49.7 bushels.

[1]Barrenness and number of ears are for independent counts and therefore do not quite agree.

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No lodging was apparent until August 26—four to seven days before the corn was ripe. On this date a very unusual wind of sixty miles per hour occurred, and another of sixty-five miles per hour on September 2. All three lots of corn withstood the windstorms about equally well.

As a grand average for both varieties planted in both ear-to-row and composite tests, (1) the disease free ears yielded 50.2 bushels, (2) the diseased ears yielded 50.6 bushels, and (3) the original untested seed yielded 49.7 bushels per acre.

TABLE 58.—*Summary showing field performance of disease free versus diseased corn as indicated by germinator test. (Average of two varieties and two methods of comparison.) 1921.*

	Disease free	Diseased	Original
Number of plats averaged	222	200	51
Number of seeds planted per plat	330	330	330
Stand 21 days after planting (per cent)	85.6	85.9	85.2
Weak plants 21 days after planting (per cent)	2.6	2.9	2.5
Number of plants per plat in fall (actual)	269.7	276.8	271.3
Per cent stand in fall	82.2	83.4	82.6
Date tasseling	7/19	7/19	7/19
Date ripe	9/3	9/3	9/3
Height of plants (inches)	107	106	107
Suckers per 100 plants	6.9	8.7	8.7
Barren plants per 100	7.5	7.3	7.8
Lodged plants per 100	84.1	83.3	83.5
Ears per 100 plants	92.8	91.9	92.4
Shelling per cent	83.5	83.7	83.4
Shrinkage of ear corn (per cent)	1.1	1.1	0.9
Yield per acre (bushels)	50.2	50.6	49.7

These data are summarized from Table 57.

In Table 59 the yields for the two varieties are so assembled as to compare the ten highest yielding ears selected for freedom from disease with the ten highest yielding ears selected as being badly diseased by means of the germinator test. The same comparisons are also made for the ten lowest yielding ears of each group. It was thought that this manner of comparing extremes for the diseased and disease free selections should emphasize any detrimental effect of the disease. The averages for both varieties indicate that the best ten ears selected for freedom from disease yielded 1.8 bushel below the diseased, while the ten lowest yielding ears selected for freedom from disease yielded 0.3 bushel more than the diseased.

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The results seem to indicate that selection for freedom from root-rot disease by the germinator test does not increase grain production under the conditions of the experiment. While these disease investigations cover only one year, yet temperature and moisture conditions thruout the corn growing season were unusually favorable for the development of this disease.

Our data suggest that agitation over the root-rot diseases of dent corn in this State would not be warranted in the present state of knowledge regarding their significance and control.

TABLE 59.—*Yields of ten highest and ten lowest yielding ears of both diseased and disease free Hogue's Yellow Dent and Nebraska White Prize corn.*

TEN HIGHEST YIELDING EARS	Yield per acre
	Bushels
Hogue's Yellow Dent selected for freedom from disease	66.8
Nebraska White Prize selected for freedom from disease	50.2
Average for both varieties	58.5
Hogue's Yellow Dent selected as badly diseased	65.2
Nebraska White Prize selected as badly diseased	55.4
Average for both varieties	60.3
TEN LOWEST YIELDING EARS	
Hogue's Yellow Dent selected for freedom from disease	48.2
Nebraska White Prize selected for freedom from disease	38.9
Average for both varieties	43.5
Hogue's Yellow Dent selected as being badly diseased	47.7
Nebraska White Prize selected as being badly diseased	38.8
Average for both varieties	43.2

SOIL AND AIR TEMPERATURES IN THE FIELD IN WHICH YIELD TESTS WERE MADE (1921)

Since the development of the rot fungi most prevalent is enhanced by warm temperature during the time of germination and early growth, continuous temperature records were taken in the cornfield thruout the growing season. These were taken by means of a combination air and soil thermograph. The air temperature was taken within a regulation instrument shelter, at a height of

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one foot above the ground. The soil temperature record is for a depth of three inches, which corresponds with the depth at which the seed was planted. The instruments were fully surrounded by a normal stand of corn in a representative portion of the field.

The data in Table 60 indicate that the soil temperatures approximated closely the prescribed temperatures for disease tests made in the germinator and were favorable for disease development. Together with the very favorable soil moisture which prevailed, this provided soil conditions conducive to the development of the rot diseases.

TABLE 60.—*Soil and air temperatures in the cornfield in which the root-rot disease studies reported in Table 57 were made. 1921.*

Week ending	Mean hourly temperatures					
	Air temperature one foot above ground			Soil temperature three inches below surface		
	[1]Night	[1]Day	Maximum	Night	Day	Maximum
(1)	*Deg. F.* (2)	*Deg. F.* (3)	*Deg. F.* (4)	*Deg. F.* (5)	*Deg. F.* (6)	*Deg. F.* (7)
May 29	75.2	84.8	94.4	73.7	76.3	83.6
June 5	69.1	71.4	80.1	71.6	73.4	78.9
June 12	71.0	79.1	85.1	74.4	78.1	85.3
June 19	78.8	87.7	94.1	83.6	86.3	93.9
June 26	74.7	81.3	91.9	83.3	82.6	91.7
July 3	80.5	84.8	97.3	83.2	82.7	89.7
July 10	74.0	80.3	88.7	77.3	78.3	81.7
July 17	74.4	79.9	85.4	82.6	83.0	86.7
July 24	70.3	76.7	81.1	77.6	77.8	80.9
July 31	72.7	79.2	85.9	79.9	80.1	84.1
August 7	64.1	70.2	76.3	74.6	74.3	77.9
August 14	72.6	83.0	89.3	74.9	75.3	78.9
August 21	70.7	77.3	82.3	74.0	74.1	78.9
August 28	75.6	80.0	90.0	77.8	77.5	82.1
September 4	81.9	83.1	96.0	78.8	77.2	81.6
Average for season	73.7	79.9	87.9	77.8	78.5	83.7

[1]Night period was from 8 P. M. to 8 A. M. Day period was from 8 A. M. to 8 P. M.

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EAR TYPE SELECTION VERSUS SELECTION FOR FREEDOM FROM ROOT-ROT DISEASES

In the preceding yield tests, 70 disease free ears and 59 badly diseased ears of Hogue's Yellow Dent corn were compared for yield in duplicate ear-to-row plats with a check plat of the original unselected corn planted after every tenth plat. The presence or absence of disease had been established previously by the recognized germinator test, and the above ears were selected as extremes from among 959 ears tested. Their selection for the yield test was based entirely upon the disease indication without reference to ear type, which had been theretofore independently determined and recorded. The ears were planted in the order of germinator testing without regard to ear type, thus distributing the various types by chance among the test

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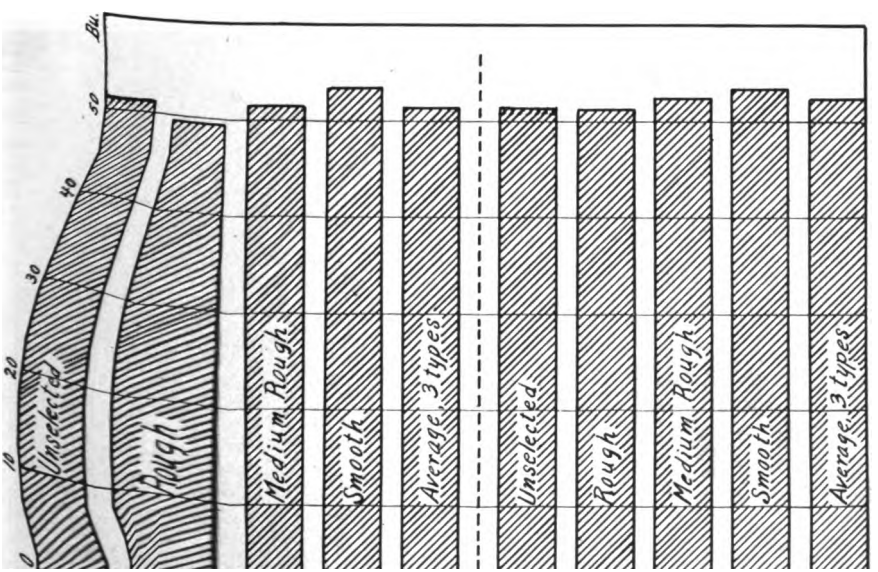
plats. Four hundred and ninety-seven ears of Nebraska White Prize corn were subjected to the same manner of testing and treatment. From among these, 39 disease free ears and 39 badly diseased ears were tested in ear-to-row plats.

The relation between type of ear planted and yield per acre in these diseased and disease free classes is shown in Table 61 and charts 6 and 7. For both varieties no advantage was found in selection for freedom from disease by the germinator test.

On the other hand, the smooth ears definitely surpassed the rough ears for both varieties, and in all cases except the disease free Nebraska White Prize they distinctly surpassed the original corn from which they were selected.

In case of the disease free Hogue's Yellow Dent, the smooth



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Rough versus smooth ears of corn selected either for presence or for absence of root-rot disease. 1921.

tion of seed	Type of ear planted							
	No. of plats averaged[1]				Grain, yield per acre			
	Rough	Medium	Smooth	Total	Rough	Medium	Smooth	All plats
1)	(2)	(3)	(4)	(5)	*Bushels* (6)	*Bushels* (7)	*Bushels* (8)	*Bushels* (9)
Dent—								
.....	44	66	30	140	55.25	58.51	61.71	58.22
.....	68	36	14	118	56.19	59.59	58.83	57.53
oth.....	.....	.....	.....	.....	55.72	59.05	60.27	57.87
e Prize—								
.....	24	38	16	78	43.58	44.61	45.26	44.20
.....	38	22	18	78	46.45	45.30	48.01	46.54
oth.....	.....	.....	.....	.....	45.01	44.95	46.63	45.37
1 varieties—								
.....	68	104	46	218	49.41	51.56	53.48	51.21
.....	104	58	32	194	51.32	52.44	53.42	52.03
oth.....	.....	.....	.....	.....	50.36	52.00	53.45	51.62
's Yellow Dent.....				28	.....			57.44
ka White Prize.....				19	.....			45.14
1.....				.....	.....			51.29

ber of ear-to-row strains represented for each type was one-half the number of plats indicated, the le in duplicate.

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ears yielded 6.46 bushels or 11 per cent more than the rough, and 4.27 bushels or 7 per cent more than the original. Of the diseased Hogue's Yellow Dent, the smooth ears yielded 2.6 bushels or 5 per cent more than the rough, and 1.39 bushels or 2 per cent more than the original.

The Nebraska White Prize disease free smooth ears surpassed the rough 1.68 bushels or 4 per cent, and yielded 0.12 bushel more than the original. In case of the diseased Nebraska White Prize, the smooth yielded 1.56 bushels or 3 per cent more than the rough, and 2.87 bushels or 6 per cent more than the original Nebraska White Prize.

These data confirm other results favoring the smoother type of ear with a somewhat shallow flinty kernel.

RELATION BETWEEN THE EAR TYPE OF THE SEED PLANTED AND OF THE CROP HARVESTED

The progeny ears produced in the ear-to-row plats of the preceding root-rot disease investigation have been classified in Table 62 to show the proportion of rough, medium, and smooth ears produced from seed ears which had been determined as being either badly diseased or disease free by means of the germi-

TABLE 62.—*Character of progeny ears harvested from the ear-to-row plats of Table 61, grouped according to the disease condition of seed ears. 1921.*

Classification of ears planted	Progeny ears showing mould or decay	Progeny ears classified according to type		
		Rough	Medium	Smooth
	Per cent	*Per cent*	*Per cent*	*Per cent*
Hogue's Yellow Dent—				
Disease free	0.00	15.8	65.1	19.1
Diseased	0.10	23.3	63.0	13.7
Original unselected	0.13	17.4	63.7	18.9
Nebraska White Prize—				
Disease free	0.10	19.4	67.4	13.2
Diseased	0.00	22.0	65.1	12.9
Original unselected	0.00	19.2	68.4	12.4
Average for both varieties—				
Disease free	0.05	17.6	66.2	16.1
Diseased	0.05	22.6	64.0	13.3
Original unselected	0.06	18.3	66.0	15.6

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TABLE 63.—*Immediate effect of the type of seed ear upon the ear type of the progeny of both diseased and disease free corn. 1921.*

Type of ear planted	Number of strains averaged	Progeny ears classified according to type		
		Rough	Medium	Smooth
	Per cent	*Per cent*	*Per cent*	*Per cent*
HOGUE'S YELLOW DENT				
Rough—				
Disease free	22	21.1	64.4	14.5
Diseased	34	27.5	62.9	9.6
Average	.....	24.3	63.7	12.0
Medium—				
Disease free	33	15.6	67.8	16.6
Diseased	18	20.4	63.6	16.0
Average	.....	18.0	65.7	16.3
Smooth—				
Disease free	15	8.3	59.4	32.3
Diseased	7	6.9	70.4	22.7
Average	.....	7.6	64.9	27.5
NEBRASKA WHITE PRIZE				
Rough—				
Disease free	12	22.7	72.0	5.3
Diseased	19	21.9	69.9	8.2
Average	.....	22.3	71.0	6.7
Medium—				
Disease free	19	13.9	73.7	12.4
Diseased	10	16.8	70.8	12.4
Average	.....	15.3	72.3	12.4
Smooth—				
Disease free	7	6.9	75.4	17.7
Diseased	8	13.0	74.9	12.1
Average	.....	9.9	75.2	14.9
AVERAGE OF BOTH VARIETIES				
Rough—				
Disease free	.....	21.9	63.2	9.9
Diseased	.....	24.7	66.4	8.9
Average	.....	23.3	64.8	9.4
Medium—				
Disease free	.....	14.7	70.8	14.5
Diseased	.....	18.6	67.2	14.2
Average	.....	16.6	69.0	14.4
Smooth—				
Disease free	.....	7.6	67.4	25.0
Diseased	.....	9.9	72.7	17.4
Average	.....	8.7	70.1	21.2

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nator test. As an average for both varieties, the disease free, diseased, and unselected corn produced respectively 17.6, 22.6, and 18.3 per cent rough ears; 16.1, 13.3, and 15.6 per cent smooth ears; and 66.2, 64.0, and 66.0 per cent of medium rough ears.

These data indicate that a slightly smoother type of corn is represented in those seed ears which had been determined to be free from root-rot disease by the germinator test. Perhaps a more important consideration brought out in Table 62 is the equal and almost insignificant amount of disease or decay present in the progeny ears of both diseased and disease free corn. Only one ear in every two thousand was noticeably affected in either case by mould or decay of any kind.

The progeny ears are further classified in Table 63 according to ear type, and show both the extent to which ear type selection tends to transmit itself in a single generation and also the relation of the ear type of the progeny to the disease condition of the seed ear.

Averaging both varieties, the rough, medium, and smooth seed ears planted produced respectively 23.3, 16.6, and 8.7 per cent rough ears in the progeny. On the other hand, the rough, medium, and smooth seed ears averaged 9.4, 14.4, and 21.2 per cent smooth ears in the progeny.

RELATION OF STAND TO YIELD OF CORN

In connection with another experiment, both Hogue's Yellow Dent and Nebraska White Prize corn have been grown for a period of years at the rates of 1, 3, and 5 plants per hill. The results are given in Tables 64 and 65. As an average for seven years, Hogue's Yellow Dent yielded 36.6, 44.6, and 40.3 bushels per acre respectively for 1, 3, and 5 plants per hill. As an average for eight years the Nebraska White Prize yielded 37.1, 52.9, and 49.4 bushels per acre.

The yield of the thin stand is augmented by an increased number of ear-bearing suckers, more 2-eared stalks, larger ears, and fewer barren plants. The reverse correlations hold for the heavy planting rate.

Hogue's Yellow Dent is a much more freely suckering variety than is Nebraska White Prize, which enables it to yield relatively better at a very thin rate of planting.

Comparative results for a four-year period with the planting rates of 1, 2, 3, 4, and 5 plants per hill are given in Table 66. The grain yields for these rates were respectively 40.7, 49.4, 52.9,

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: 64.—*Relative growth and yield of corn grown at thin, medium, and thick rates of planting. Hogue's Yellow Dent. 1911-1917.*

ts ill	Plants per acre	Yield of grain per acre							
		1911	1912	1913	1914	1915	1916	1917	Average
	(2)	*Bushels* (3)	*Bushels* (4)	*Bushels* (5)	*Bushels* (6)	*Bushels* (7)	*Bushels* (8)	*Bushels* (9)	*Bushels* (10)
....	3,556	34.4	49.0	10.2	42.9	57.6	33.7	28.6	36.6
....	10,668	55.3	38.4	6.6	44.8	79.8	37.1	50.0	44.6
....	17,780	53.7	27.5	3.8	32.0	80.6	28.3	56.3	40.3

nts hill	Summary of plant characteristics for period								
	Stalk height	Ear height	Date ripe	Lodging	2-eared stalks per 100 plants	Ears per 100 plants	Suckers per 100 plants	Shrinkage of ear corn	Shelling per cent
)	*Inches* (11)	*Inches* (12)	(13)	*Per cent* (14)	(15)	(16)	(17)	*Per cent* (18)	*Per cent* (19)
.....	88	45	9/24	11	39	170	101	10.5	83.2
.....	88	44	9/23	26	11	86	25	10.1	83.6
.....	88	43	9/22	35	8	63	10	10.3	82.1

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TABLE 65.—*Relative growth and yield of corn grown at thin, medium, and thick rates of planting.* Nebraska White Prize corn, 1912-1917 and 1920-1921.

Plants per hill	Plants per acre	Yield of grain per acre								
		1912	1913	1914	1915	1916	1917	1920	1921	Average
(1)	(2)	*Bushels* (3)	*Bushels* (4)	*Bushels* (5)	*Bushels* (6)	*Bushels* (7)	*Bushels* (8)	*Bushels* (9)	*Bushels* (10)	*Bushels* (11)
1	3,556	54.3	14.3	40.0	42.6	32.9	29.0	35.5	48.1	37.1
3	10,668	53.8	11.7	51.5	86.0	54.2	51.0	53.6	61.3	52.9
5	17,780	51.8	6.7	36.1	97.2	42.1	50.4	51.5	59.4	49.4

Plants per hill	Summary of plant characteristics for 1915-1917 and 1920-1921								
	Stalk height	Ear height	Date ripe	Lodging	2-eared stalks per 100 plants	Ears per 100 plants	Suckers per 100 plants	Shrinkage of ear corn	Shelling per cent
(1)	*Inches* (12)	*Inches* (13)	(14)	*Per cent* (15)	(16)	(17)	(18)	*Per cent* (19)	*Per cent* (20)
1	103	53	9/20	8	28	148	59	7.7	80.8
3	101	49	9/20	28	18	104	16	7.7	81.4
5	100	49	9/19	37	4	78	4	7.9	81.2

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50.7, and 49.3 bushels per acre. It is very evident that there may be a considerable variation in stand, fluctuating about three per hill, without a material effect upon yield. A stand ranging from about 2.5 to 3.0 plants per hill appears to be optimum for local varieties under Experiment Station conditions. This rate should be gradually reduced from the eastern toward the western part of the State.

In these rates of planting tests, the corn had been planted thick and thinned so as to insure the actual stand of plants indicated.

TABLE 66.—*Comparative yields of Hogue's Yellow Dent corn planted at the rates of 1, 2, 3, 4, and 5 plants per hill. 1914-1917.*

Plants per hill	Plants per acre	Yield of grain per acre				
		1914	1915	1916	1917	Average
(1)	(2)	*Bushels* (3)	*Bushels* (4)	*Bushels* (5)	*Bushels* (6)	*Bushels* (7)
1	3,556	42.9	57.6	33.7	28.6	40.7
2	7,112	48.2	69.7	35.2	44.5	49.4
3	10,668	44.8	79.8	37.1	50.0	52.9
4	14,224	36.1	80.3	33.1	53.4	50.7
5	17,780	32.0	80.6	28.3	56.3	49.3

RELATION OF UNIFORMITY OF STAND TO YIELD OF CORN

During the five years 1915-1917 and 1920-1921, an investigation was made to determine the effect of varied distribution of plants upon the yield of grain per acre. While the number of plants per acre was the same in all cases, the number of plants in adjacent hills differed. The methods of distribution compared were as follows: (1) All hills with uniformly three plants, (2) alternating hills with two and four plants, (3) alternating hills with one, three, and five plants, and (4) alternating hills with one, two, three, four, and five plants.

The results given in Table 67 indicate that the three irregular distributions averaged 58 bushels per acre as compared with 59 bushels for the uniformly three plants per hill rate. Alternating hills with two and four plants yielded fully as well as did uniformly three plants per hill. Alternating hills of one, two, three, four, and five plants per hill yielded 0.4 bushel less, and

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TABLE 67.—*Effect of an uneven stand upon the yield of corn. Five-year average, 1915-1917 and 1920-1921.*

Distribution of plants in successive hills	Plants per acre	Yield of grain per acre					
		1915	1916	1917	1920	1921	Av.
(1)	(2)	*Bu.* (3)	*Bu.* (4)	*Bu.* (5)	*Bu.* (6)	*Bu.* (7)	*Bu.* (8)
Uniformly 3 plants	10,668	93.4	55.2	26.7	52.3	66.7	59.0
Alternating 2 and 4 plants	10,668	89.8	58.4	28.1	51.9	68.0	59.2
Alternating 1, 3, 5 plants	10,668	88.0	52.4	26.3	48.9	64.3	56.0
Alternating 1, 2, 3, 4, 5 plants	10,668	95.1	54.4	30.6	50.2	62.9	58.6

Hogue's Yellow Dent was grown in this test during the first three years and Nebraska White Prize thereafter.

the alternating hills of one, three, and five plants yielded 3.0 bushels less.

These data suggest that corn plants, of the larger varieties at least, draw upon the soil fertility and moisture for such a distance that considerable irregularity in stand may exist without markedly affecting the yield.

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RESEARCH BULLETIN NO. 21

THE UNIVERSITY OF NEBRASKA

BULLETIN

OF THE

AGRICULTURAL EXPERIMENT STATION

OF

NEBRASKA

STUDIES OF IMMUNITY AGAINST HEMORRHAGIC SEPTICEMIA

By L. Van Es and H. M. Martin

Department of Animal Pathology and Hygiene

August, 1922

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STUDIES OF IMMUNITY AGAINST HEMORRHAGIC SEPTICEMIA

L. VAN ES AND H. M. MARTIN

DEPARTMENT OF ANIMAL PATHOLOGY AND HYGIENE

Within recent years a considerable interest has been developed in the part played by Bacillus bipolaris septicus in the production of disease among farm live stock. Hemorrhagic septicemia was and is yet represented to be a prolific source of loss among the domesticated mammals. So far as our own observations pertaining to Nebraska live stock are concerned, there does not seem to be cause to attach great importance to this disease as a menace to cattle, sheep, and swine. In our investigations we very rarely encountered this infection, in spite of considerable effort to do so and in spite of an abundance of suspected material from cattle, sheep, and swine.

In only one direction can we recognize the organism as a serious source of loss, and that is in connection with fowl cholera, a disease which exacts a heavy annual toll from our poultry raisers.

It is this last named disease above all which gives warrant for a study of the immunology of hemorrhagic septicemia in general.

As one of the phases of our inquiry an effort was made to acquire some general knowledge regarding the immunizing value (1) of sera prepared with the aid of Bacillus bipolaris septicus procured from cattle and swine or (2) of those alleged to be of service in the control or treatment of hemorrhagic septicemia in the species mentioned. The experiments reported in this publication were almost exclusively made with sera purchased from dealers in biologic products.

The sera examined were prepared by means of strains of Bacillus bipolaris septicus obtained from cattle and swine or which were represented, at least, to be useful in the management of hemorrhagic septicemia in the species named.

In the test of the sera (1) represented to be useful in the control of the disease in cattle or (2) which were prepared by means of a cattle strain of the Bacillus bipolaris septicus, use was made of cultures of our cattle strain No. 620, while in

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the series (1) pertaining to the sera intended to be used in swine or (2) made with the aid of strains derived from swine, our swine strain No. 59 was employed. The virus used always consisted of bouillon cultures at the end of a twenty-four hour incubation.

Rabbits were used as test animals. The serum was injected subcutaneously, while the virus was injected intravenously. The intravenous virus injections were preferred after previous experiments had shown that in this manner the annoying formation of abscesses and necrotic areas could be avoided, while the difference between the results obtained with intravenous virus injections and subcutaneous ones was only expressed by a slightly shorter incubation period in the case of the former.

For so far as this was possible each serum was utilized in two test series. In one of them there was variation in the doses of serum given. All the animals in this series received the serum on a given day, while the virus was injected twenty-four hours later. In the other series all the rabbits received ten c.c. of serum on a given day. The series was then divided into four or five groups, each of which received the required amount of virus at periods from three to five days apart.

In the first series the influence of the amounts of serum was taken into consideration, while in the latter we aimed to obtain information regarding the duration of the passive immunity, in case any should be manifest at all.

Second injections of virus were given to all surviving animals, usually some two weeks after the first virus injection was administered, with a view of ascertaining whether or not the subsequent injection of virus into a serum protected animal would engender a more enduring and active immunity.

BOVINE STRAIN SERA

The first series comprises the tests made with varying doses

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TABLE 1.

1921 No. 1052

Rabbit No.	Injection of serum No. 1052, Feb. 11, c.c.	Injection of virus No. 620, Feb. 12, 1/500 c.c.	Injection of virus No. 620, Feb. 27, 1/600 c.c.	Dates of deaths	Remarks
1	15	+	+	March 1	
2	15	+	+	Feb. 28	
3	15	+	+	Feb. 28	
4	10	+	+	March 1	
5	10	+	+	March 2	
6	10	+	+	March 1	
7	5	+	+	March 1	
8	5	+	+	March 1	
9	5	+	—	Feb. 18	
10	2.5	+	—	Feb. 17	
11	2.5	+	+	March 2	
12	2.5	+	—	Feb. 18	

NOTE—The fact that an injection was made is indicated by the +. A dash (—) is used to show that no injection took place.

TABLE 2.

1921 (Normal) No. 1052

Rabbit No.	Injection of normal serum, Feb. 11, c.c.	Injection of virus No. 620, Feb. 12, 1/500 c.c.	Injection of virus No. 620, Feb. 27, 1/600 c.c.	Dates of deaths	Remarks
1	15	+	—	Feb. 17	
2	15	+	+	March 7	
3	15	+	—	Feb. 14	
4	10	+	—	Feb. 14	
5	10	+	—	Feb. 15	
6	10	+	—	Feb. 14	
7	5	+	—	Feb. 14	
8	5	+	—	Feb. 14	
9	5	+	—	Feb. 15	
10	2.5	+	—	Feb. 15	
11	2.5	+	—	Feb. 14	
12	2.5	+	+	?	Record of date of death lost.

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1921 TABLE 3. No. 1052

Rabbit No.	Injection of virus No. 620, Feb. 12, 1/500 c.c.	Dates of deaths	Remarks
1	+	Feb. 14	Virus control (first injections)
2	+	Feb. 14	
3	+	Feb. 14	

1921 TABLE 4. No. 1052

Rabbit No.	Injection of virus No. 620, Feb. 27, 1/600 c.c.	Dates of deaths	Remarks
1	+	Feb. 28	Virus control (second injections)
2	+	Mch. 1	

1921 TABLE 5. No. 1178

Rabbit No.	Injection of serum No. 1178, April 11, c.c.	Injection of virus No. 620, April 12, 1/500 c.c.	Injection of virus No. 620, April 26, 1/600 c.c.	Dates of deaths	Remarks
1	15	+	+	Apr. 27	
2	15	+	—	Apr. 19	B. bipolaris swarming in blood. Pericarditis. Necrotic pneumonia. Empyema.
3	15	+	—	Apr. 17	Severe pneumonia. Heart blood swarming with B. bipolaris.
4	15	+	—	Apr. 20	Pneumonia. Heart blood swarming with B. bipolaris.
5	10	+	+	Apr. 30	
6	10	+	—	Apr. 18	Few B. bipolaris in heart blood.
7	10	+	+	Apr. 28	
8	10	+	—	Apr. 16	Fibrinous pericarditis. Pneumonia. Abscess in lung. Blood swarming with B. bipolaris.
9	5	+	+	Apr. 27	
10	5	+	+	Apr. 27	
11	5	+	+	Apr. 28	
12	5	+	+	Apr. 28	
13	—	+	—	Apr. 13	Control 1st test.
14	—	+	—	Apr. 14	Control 1st test.
15	—	+	—	Apr. 14	Control 1st test.
16	—	+	+	Apr. 28	Control 1st test.
17	—	—	+	—	Control 2nd test. Lives.
18	—	—	+	Apr. 28	Control 2nd test.

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1922 TABLE 6. No. 1178

Rabbit No.	Injection of serum No. 1178, Feb. 6, c.c.	Injection of virus No. 620, Feb. 7, 1/500 c.c.	Injection of virus No. 620, Feb. 22, 1/500 c.c.	Dates of deaths	Remarks
1	5	+	+	Feb. 25	
2	5	+	+	Feb. 25	
3	5	+	—	Feb. 12	
4	10	+	—	Feb. 13	
5	10	+	—	Feb. 15	
6	10	+	—	Feb. 15	
7	15	+	+	Feb. 25	
8	15	+	—	Feb. 15	
9	15	+	+	March 6	Heart blood swarming with B. bipolaris.

1922 TABLE 7. No. 1434

Rabbit No.	Injection of serum No. 1434, Feb. 6, c.c.	Injection of virus No. 620, Feb. 7, 1/500 c.c.	Injection of virus No. 620, Feb. 22, c.c.	Dates of deaths	Remarks
1	5	+	—	Feb. 13	
2	5	+	—	Feb. 13	
3	5	+	—	Feb. 12	
4	10	+	—	Feb. 13	
5	10	+	+	Feb. 24	
6	10	+	—	Feb. 14	
7	15	+	+	Feb. 24	
8	15	+	+	Feb. 24	
9	15	+	+	Feb. 25	

1922 TABLE 8. No. 1828

Rabbit No.	Injection of serum No. 1828, Feb. 6, c.c.	Injection of virus No. 620, Feb. 7, 1/500 c.c.	Injection of virus No. 620, Feb. 22, 1/500 c.c.	Dates of deaths	Remarks
1	5	+	—	Feb. 14	
2	5	+	—	Feb. 14	
3	5	+	—	Feb. 13	
4	10	+	—	Feb. 19	
5	10	+	+	Feb. 23	
6	10	+	—	Feb. 14	
7	15	+	+	Feb. 23	
8	15	+	—	Feb. 16	
9	15	+	—	Feb. 15	

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1922 TABLE 9. No. 1829

Rabbit No.	Injection of serum No. 1829, Feb. 6, c.c.	Injection of virus No. 620 Feb. 7, 1/500 c.c.	Dates of deaths	Remarks
1	5	+	Feb. 10	
2	5	+	Feb. 10	
3	5	+	Feb. 9	
4	10	+	Feb. 13	
5	10	+	Feb. 12	
6	10	+	Feb. 11	
7	15	+	Feb. 11	
8	15	+	Feb. 12	
9	15	+	Feb. 14	

1922 TABLE 10. No. 1830

Rabbit No.	Injection of serum No. 1830, Feb. 6, c.c.	Injection of virus No. 620, Feb. 7, 1/500 c.c.	Dates of deaths	Remarks
1	5	+	Feb. 10	
2	5	+	Feb. 10	
3	5	+	Feb. 8	
4	10	+	Feb. 8	
5	10	+	Feb. 13	
6	10	+	Feb. 10	
7	15	+	Feb. 13	
8	15	+	Feb. 11	
9	15	+	Feb. 10	

TABLE 11.

1922 Controls 1178—1434—1828—1829—1830

Rabbit No.	Injection of virus No. 620, Feb. 7, 1/500 c.c.	Dates of deaths	Remarks
1	+	Feb. 8	
2	+	Feb. 8	

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The results of the preceding tests are summarized in Tables 12 and 13 and they show that the protective influence of the serum was quite manifest, altho it does not appear that the variation in the doses as used in the series was very strikingly shown in the totals. There were differences, but they were neither conspicuous nor consistent. There appears, however, to be a marked difference in the potency of some of the sera examined. The tables show that protective influence of the sera examined manifested itself in two ways,—in the first place by actually preventing the death of experimental animals when injected with virulent cultures, and in the second place by increasing the approximate surviving period, after virus inoculation, of the serum-treated animals which actually succumbed, as compared with the ones treated with normal serum and with those which served as virus controls.

Of the 69 rabbits treated with serum and virus, 26 survived. Approximately two weeks after the latter had received the first virus injection, they were inoculated again with the same virus.

Table No. 14 shows that none of those survivors had become resistant to infection as a result of the serum-virus treatment they had previously received. A certain lengthening of the surviving periods after the last virus injection could be observed. (See Table 15.)

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TABLE 12.

Results of virus injections made one day after serum injected in the following doses.

Serum No.	15 c.c.		10 c.c.		5 c.c.		2.5 c.c.		All doses	
	Dead	Alive	Dead	Alive	Dead	Alive	Dead	Alive	Dead	Alive
1052	0	3	0	3	1	2	2	1	3	9
1178	3	1	2	2	0	4	—	—	5	7
1178	1	2	3	0	1	2	—	—	5	4
1434	0	3	2	1	3	0	—	—	5	4
1828	2	1	2	1	3	0	—	—	7	2
1829	3	0	3	0	3	0	—	—	9	0
1830	3	0	3	0	3	0	—	—	9	0
Totals	12	10	15	7	14	8	2	1	43	26
Normal 1052	2	1	3	0	3	0	2	1	10	2

Results of virus injections without preceding serum injections.

Controls belonging to:										
1052	—	—	—	—	—	—	—	—	3	0
1178	—	—	—	—	—	—	—	—	3	0
1178	—	—	—	—	—	—	—	—		
1434	—	—	—	—	—	—	—	—		
1828	—	—	—	—	—	—	—	—	10	0
1829	—	—	—	—	—	—	—	—		
1830	—	—	—	—	—	—	—	—		
Totals	—	—	—	—	—	—	—	—	16	0

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TABLE 13.

Lengths of surviving periods of animals which died on account of virus injections on the day following serum treatment.

Serum No.	Approximate averages of surviving periods by hours									
	15 c.c.		10 c.c.		5 c.c.		2.5 c.c.		All doses	
	No. of rabbits	Surviving periods	No. of rabbits	Surviving periods	No. of rabbits	Surviving periods	No. of rabbits	Surviving periods	No. of rabbits	Surviving periods
1052.....	—	—	—	—	1	168	2	156	3	160
1178.....	1	192	3	176	1	120	—	—	5	168
1178.....	3	160	2	120	—	—	—	—	5	144
1434.....	—	—	2	156	3	136	—	—	5	144
1828.....	2	204	2	228	3	160	—	—	7	192
1829.....	3	128	3	120	3	64	—	—	9	104
1830.....	3	104	3	80	3	56	—	—	9	80
Totals and av'gs	12	148	15	142	14	109	2	156	43	134
Normal 1052.....	2	84	3	56	3	56	—	—	8	63

Results of virus injections in animals not treated with serum.

Controls belonging to:										
1952.....	—	—	—	—	—	—	—	—	3	48
1178.....	—	—	—	—	—	—	—	—	3	64
1178.....	—	—	—	—	—	—	—	—	10	24
1434.....	—	—	—	—	—	—	—	—		
1828.....	—	—	—	—	—	—	—	—		
1829.....	—	—	—	—	—	—	—	—		
1830.....	—	—	—	—	—	—	—	—		
Totals and av'gs	—	—	—	—	—	—	—	—	16	36

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TABLE 14.

Results of second virus injections in serum-virus treated rabbits.

Serum No.	15 c.c.		10 c.c.		5 c.c.		2.5 c.c.		All doses	
	Dead	Alive	Dead	Alive	Dead	Alive	Dead	Alive	Dead	Alive
1052	3	0	3	0	2	0	1	0	9	0
1178	1	0	2	0	4	0	—	—	7	0
1178	2	0	0	0	2	0	—	—	4	0
1434	3	0	1	0	0	0	—	—	4	0
1828	1	0	1	0	0	0	—	—	2	0
1829	0	0	0	0	0	0	—	—	0	0
1830	0	0	0	0	0	0	—	—	0	0
Totals	10	0	7	0	8	0	1	0	26	0
Normal 1052	1	0	0	0	0	0	1	0	2	0
Virus controls	—	—	—	—	—	—	—	—	2	0
	—	—	—	—	—	—	—	—	1	1
	—	—	—	—	—	—	—	—	1	0
	—	—	—	—	—	—	—	—	1	0
	—	—	—	—	—	—	—	—	1	0
	—	—	—	—	—	—	—	—	2	0
Totals	—	—	—	—	—	—	—	—	8	1

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TABLE 15.

Lengths of surviving periods of animals which were serum-virus treated and which died as a result of a second virus injection.

Serum No.	Approximate averages of surviving periods by doses and hours							
	15 c.c.		10 c.c.		5 c.c.		All doses	
	No. of rabbits	Surviving periods	No. of rabbits	Surviving periods	No. of rabbits	Surviving periods	No. of rabbits	Surviving periods
1052.....	3	32	3	56	2	48	8	45
1178.....	1	24	2	72	4	36	7	44+
1178.....	2	180	—	—	2	72	4	126
1434.....	3	56	1	48	—	—	4	54
1828.....	1	24	1	24	—	—	2	24
Totals and averages..	10	67	7	55	8	48	25	57
Virus control..	—	—	—	—	—	—	8	30

Tables Nos. 16-23 exhibit the details of the series in which a uniform dose of serum was given and the latter followed by the virus inoculation of the various groups at times further and further removed from the day of serum treatment.

The results of the experiments set forth in Tables 16-23 are summarized in Table 24. They indicate that the animals used in the experiment survived only exceptionally when the virus dose was given from one to several days after the serum injections.

The influence of the serum in the series is only shown by the lengthening of the surviving periods of the treated rabbits. This phenomenon is shown in Table 25. In comparison with the virus-control rabbits, there is a marked tendency on the part of the serum-treated animals to survive longer after the virus inoculations. The differences gradually disappear as the periods elapsing between the injections of the serum and those of the virus become longer. This behavior is shown by

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1921 TABLE 16. No. 1052

Rabbit No.	Injection of serum No. 1052, March 17, c.c.	Injection of virus No. 620, 1/500 c.c. Dates	Dates of deaths	Remarks
1	10	Mch. 18	Mch. 28	Heart blood swarming with B. bipolaris.
2	10	Mch. 18	Mch. 25	
3	—	Mch. 18	Mch. 20	Control.
4	—	Mch. 18	Mch. 20	Control.
5	10	Mch. 21	Mch. 27	Few organisms in heart blood, but abscess at point of inoculation swarming with same.
6	10	Mch. 21	Mch. 27	Very few B. bipolaris in blood.
7	—	Mch. 21	Mch. 22	Control.
8	—	Mch. 21	Mch. 23	Control.
9	10	Mch. 25	April 1	B. bipolaris in blood.
10	10	Mch. 25	Mch. 29	Few B. bipolaris in blood.
11	—	Mch. 25	Mch. 28	Control.
12	—	Mch. 25	Mch. 27	Control.
13	10	Mch. 28	Mch. 31	B. bipolaris in blood.
14	10	Mch. 28	Mch. 31	B. bipolaris in blood.
15	—	Mch. 28	Mch. 29	Control.
16	—	Mch. 28	Mch. 30	Control.
17	10	Mch. 31	April 5	Numerous B. bipolaris in blood.
18	10	Mch. 31	April 2	B. bipolaris in blood.
19	—	Mch. 31	April 2	Control.
20	—	Mch. 31	April 2	Control.

1921 TABLE 17. No. 1440

Rabbit No.	Injection of serum No. 1440, Jan. 16, 10 c.c.	Injection of virus No. 620, 1/500 c.c.					Dates of deaths	Remarks
		8/19	8/23	8/27	8/31	9/3		
1	+	+	—	—	—	—	Aug. 25	
2	+	+	—	—	—	—	Aug. 23	
3	—	+	—	—	—	—	Aug. 20	
4	—	+	—	—	—	—	Aug. 20	
5	+	—	+	—	—	—	Aug. 25	
6	+	—	+	—	—	—	Aug. 25	
7	—	—	+	—	—	—	Aug. 25	
8	—	—	+	—	—	—	Aug. 26	
9	+	—	—	+	—	—	Aug. 28	
10	+	—	—	+	—	—	Aug. 28	
11	—	—	—	+	—	—	Aug. 28	
12	—	—	—	+	—	—	Aug. 28	
13	+							

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TABLE 18.

1921 No. 1522

Rabbit No.	Injection of serum No. 1522, Aug. 16, 10 c.c.	Injections of virus No. 620, 1/500 c.c.		Dates of deaths	Remarks
		8/23	8/27		
1	+	+	—	Aug. 25	
2	+	+	—	Aug. 25	
3	+	+	—	Aug. 25	
4	—	+	—	Aug. 25	
5	—	+	—	Aug. 26	
6	+	—	+	Aug. 28	
7	+	—	+	Aug. 28	
8	—	—	+	Aug. 28	
9	—	—	+	Aug. 28	

TABLE 19.

1922 No. 1178

Rabbit No.	Injection of serum No. 1178, Feb. 6, 10 c.c.	Injection of virus No. 620, 1/500 c.c.				Dates of deaths	Remarks
		2/10	2/14	2/18	2/22		
1	+	+	—	—	—	Feb. 14	
2	+	+	—	—	—	Feb. 17	
3	+	+	—	—	—	Feb. 16	
4	—	+	—	—	—	Feb. 10	
5	—	+	—	—	—	Feb. 11	
6	+	—	+	—	—	Feb. 16	
7	+	—	+	—	—	Feb. 16	
8	+	—	+	—	—	Feb. 15	
9	—	—	+	—	—	Feb. 15	
10	—	—	+	—	—	Feb. 15	
11	+	—	—	+	—	Feb. 19	
12	+	—	—	—	—	Feb. 17	Probable cause of death, abscess of head.
13	+	—	—	+	—	Feb. 19	
14	—	—	—	+	—	Feb. 19	
15	+	—	—	—	+	Feb. 24	
16	+	—	—	—	+	Feb. 23	
17	+	—	—	—	+	Feb. 24	
18	—	—	—	—	+	Feb. 23	

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1922 TABLE 20. No. 1434

Rabbit No.	Injection of serum No. 1434, Feb. 6, 10 c.c.	Injection of virus No. 620, 1/500 c.c.				Dates of deaths	Remarks
		2/10	2/14	2/18	2/22		
1	+	+	—	—	—	Feb. 14	
2	+	+	—	—	—	Feb. 13	
3	+	+	—	—	+	Feb. 23	
4	—	+	—	—	—	Feb. 11	
5	—	+	—	—	—	Feb. 11	
6	+	—	+	—	—	Feb. 17	
7	+	—	+	—	—	Feb. 16	
8	+	—	+	—	—	Feb. 16	
9	—	—	+	—	—	Feb. 15	
10	—	—	+	—	—	Feb. 15	
11	+	—	—	+	—	Feb. 19	
12	+	—	—	+	—	Feb. 19	
13	+	—	—	+	+	Feb. 25	
14	—	—	—	+	—	Feb. 19	
15	+	—	—	—	+	Feb. 23	
16	+	—	—	—	+	Feb. 23	
17	+	—	—	—	+	Feb. 23	
18	—	—	—	—	+	Feb. 23	

1922 TABLE 21. No. 1828

Rabbit No.	Injection of serum No. 1828, Feb. 6, 10 c.c.	Injection of virus No. 620, 1/500 c.c.				Dates of deaths	Remarks
		2/10	2/14	2/18	2/22		
1	+	+	—	—	—	Feb. 17	
2	+	+	—	—	—	Feb. 17	
3	+	+	—	—	—	Feb. 14	
4	—	+	—	—	—	Feb. 11	
5	—	+	—	—	—	Feb. 11	
6	+	—	+	—	—	Feb. 15	
7	+	—	+	—	—	Feb. 16	
8	+	—	+	—	—	Feb. 15	
9	—	—	+	—	—	Feb. 15	
10	—	—	+	—	—	Feb. 15	
11	+	—	—	+	—	Feb. 19	
12	+	—	—	+	—	Feb. 19	
13	+	—	—	+	—	Feb. 19	
14	—	—	—	+	—	Feb. 19	
15	+	—	—	—	+	Feb. 23	
16	+	—	—	—	+	Feb. 24	
17	+	—	—	—	+	Feb. 23	

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1922 TABLE 22. No. 1829

Rabbit No.	Injection of serum No. 1829, Feb. 6, 10 c.c.	Injection of virus No. 620, 1/500 c.c.				Dates of deaths	Remarks
		2/10	2/14	2/18	2/22		
1	+	+	—	—	—	Feb. 11	
2	+	+	—	—	—	Feb. 11	
3	+	+	—	—	—	Feb. 12	
4	—	+	—	—	—	Feb. 11	
5	—	+	—	—	—	Feb. 11	
6	+	—	+	—	—	Feb. 15	
7	+	—	+	—	—	Feb. 15	
8	+	—	+	—	—	Feb. 15	
9	—	—	+	—	—	Feb. 15	
10	—	—	+	—	—	Feb. 15	
11	+	—	—	+	—	Feb. 19	
12	+	—	—	+	—	Feb. 20	
13	+	—	—	+	—	Feb. 19	
14	—	—	—	+	+	Mch. 4	
15	—	—	—	—	+	Feb. 23	
16	+	—	—	—	+	Feb. 23	
17	+	—	—	—	+	Feb. 24	
18	+	—	—	—	+	Feb. 23	

1922 TABLE 23. No. 1830

Rabbit No.	Injection of serum No. 1830, Feb. 6, 10 c.c.	Injection of virus No. 620, 1/500 c.c.				Dates of deaths	Remarks
		2/10	2/14	2/18	2/22		
1	+	+	—	—	—	Feb. 13	
2	+	+	—	—	—	Feb. 13	
3	+	+	—	—	—	Feb. 13	
4	—	+	—	—	—	Feb. 11	
5	—	+	—	—	—	Feb. 11	
6	+	—	+	—	—	Feb. 16	
7	+	—	+	—	—	Feb. 15	
8	+	—	+	—	—	Feb. 15	
9	—	—	+	—	—	Feb. 15	
10	—	—	+	—	—	Feb. 15	
11	+	—	—	+	—	Feb. 19	
12	+	—	—	+	—	Feb. 19	
13	+	—	—	+	—	Feb. 19	
14	—	—	—	+	—	Feb. 19	
15	+	—	—	—	+	Feb. 24	
16	+	—	—	—	+	Feb. 23	
17	+	—	—	—	+	Mch. 8	
18	—	—	—	—	+	Feb. 23	

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the graph in Table 26, which tends to show that the small degree of protection conferred by the serum has practically disappeared after a lapse of seven or eight days.

TABLE 24.

Results of virus inoculations of serum-treated rabbits after varying periods.

Injection of 10 c.c. of serum No.	Virus injection after serum. Days	Serum-treated rabbits		Virus-control rabbits		Remarks
		Alive	Dead	Alive	Dead	
1052	1	0	2	0	2	
	4	0	2	0	2	
	8	0	2	0	2	
	11	0	2	0	2	
	14	0	2	0	2	
1440	3	0	2	0	2	
	7	0	2	0	2	
	11	0	2	0	2	
	15	0	2	0	2	
	18	1	0	1	0	
1522	7	0	3	0	2	
	11	0	2	0	2	
1178	4	0	3	0	2	
	8	0	3	0	2	
	12	0	2	0	1	
	16	0	3	0	1	
1434	4	1	2	0	2	
	8	0	3	0	2	
	12	1	2	0	1	
	16	0	3	0	1	
1828	4	0	3	0	2	
	8	0	3	0	2	
	12	0	3	0	1	
	16	0	3	0	1	
1829	4	0	3	0	2	
	8	0	3	0	2	
	12	0	3	1	0	
	16	0	3	0	1	
1830	4	0	3	0	2	
	8	0	3	0	2	
	12	0	3	0	1	
	16	0	3	0	1	

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TABLE 25.

The average surviving periods of rabbits dead as the result of virus injections at varying periods after serum treatment, in hours.

Injection of 10 c.c. of serum No.	Virus injection after serum. Days	Serum-treated rabbits		Virus-control rabbits		Remarks
		No. of rabbits	Surviving periods	No. of rabbits	Surviving periods	
1052.....	1	2	204	2	48	
	4	2	144	2	36	
	8	2	132	2	60	
	11	2	72	2	36	
	14	2	84	2	48	
1440.....	3	2	120	2	24	
	7	2	48	2	60	
	11	2	24	2	24	
	15	2	36	2	24	
1522.....	7	3	48	2	36	
	11	2	24	2	24	
1178.....	4	3	136	2	24	
	8	3	40	2	24	
	12	2	24	1	24	
	16	3	40	1	24	
1434.....	4	2	84	2	24	
	8	3	56	2	24	
	12	2	24	1	24	
	16	3	24	1	24	
1828.....	4	3	144	2	24	
	8	3	32	2	24	
	12	3	24	1	24	
	16	3	32	1	24	
1829.....	4	3	32	2	24	
	8	3	24	2	24	
	12	3	32	1	336	
	16	3	32	1	24	
1830.....	4	3	72	2	24	
	8	3	32	2	24	
	12	3	24	1	24	
	16	3	136	1	24	

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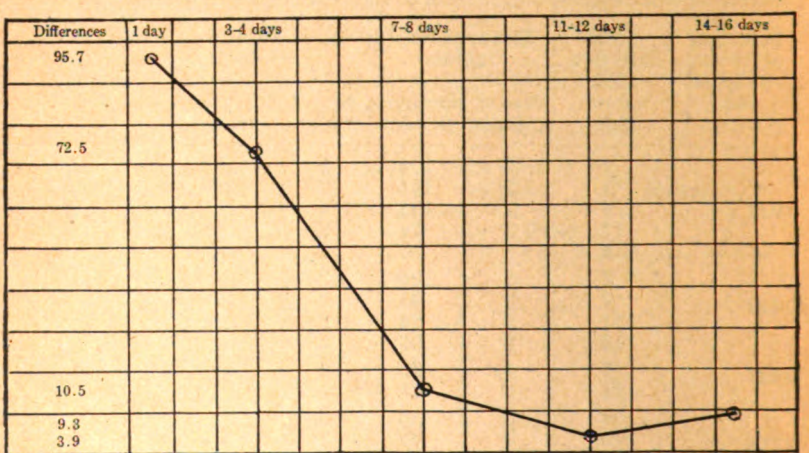
TABLE 26.

Differences, in hours, between surviving periods of serum-treated rabbits and of corresponding virus-control rabbits at varying periods after serum treatment.



N. B. The evidence of one virus-control rabbit lingering 336 hrs. and of one serum-treated rabbit lingering 408 hrs. was not included in this graph.

SWINE STRAIN SERA

In this series the same general plan of inquiry as reported on the preceding pages was followed. The first part of the tests made pertain to sera which were injected in varying doses. In one of the tests (No. 1053) a control set of rabbits injected with normal serum was used in order to be able to estimate whatever

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TABLE 27.

1921 No. 1053

Rabbit No.	Injection of serum No. 1053, Feb. 11, c.c.	Injection of virus No. 59, Feb. 12, 1/5,000 c.c.	Injection of virus No. 59, Feb. 27, 1/6,000 c.c.	Dates of deaths	Remarks
1	15	+	+	Feb. 28	
2	15	+	+	Feb. 28	
3	15	+	+	Mch. 1	
4	10	+	+	Mch. 1	
5	10	+	+	Feb. 28	
6	10	+	+	Feb. 28	
7	5	+	—	Feb. 15	
8	5	+	+	Feb. 28	
9	5	+	+	Feb. 28	
10	2.5	+	+	Feb. 28	
11	2.5	+	+	Mch. 7	
12	2.5	+	+	Mch. 1	

TABLE 28.

1921 (Normal serum) No. 1053

Rabbit No.	Injection of normal serum, Feb. 11, c.c.	Injection of virus No. 59, Feb. 12, 1/5,000 c.c.	Injection of virus No. 59, Feb. 27, 1/6,000 c.c.	Dates of deaths	Remarks
1	15	+	—	Feb. 14	
2	15	+	—	Feb. 14	
3	15	+	—	Feb. 17	
4	10	+	—	Feb. 15	
5	10	+	—	Feb. 15	
6	10	+	—	Feb. 15	
7	5	+	—	Feb. 16	
8	5	+	—	Feb. 14	
9	5	+	—	Feb. 14	
10	2.5	+	—	Feb. 20	
11	2.5	+	—	Feb. 14	
12	2.5	+	—	Feb. 15	

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TABLE 29.

1921 No. 1053

Rabbit No.	Injection of virus No. 59, February 12, 1/5,000 c.c.	Dates of deaths	Remarks
1	+	Feb. 18	Virus control (first injection).
2	+	Feb. 14	Virus control (first injection).
3	+	Feb. 14	Virus control (first injection).

TABLE 30.

1921 No. 1053

Rabbit No.	Injection of virus No. 59, February 27, 1/6,000 c.c.	Dates of deaths	Remarks
1	+	Feb. 28	Virus control (second injections).
2	+	Feb. 28	Virus control (second injections).

TABLE 31.

1921 No. 1433

Rabbit No.	Injection of serum No. 1433, Aug. 26, c.c.	Injection of virus No. 59, Aug. 27, 1/5,000 c.c.	Injection of virus No. 59, Sept. 9, 1/6,000 c.c.	Dates of deaths	Remarks
1	5	+	—	Sept. 8	
2	5	+	—	Aug. 29	
3	5	+	—	Sept. 1	
4	10	+	—	Aug. 31	
5	10	+	+	Sept. 10	
6	10	+	—	Sept. 2	

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TABLE 32.

1921 No. 1436

Rabbit No.	Injection of serum No. 1436, Sept. 9, c.c.	Injection of virus No. 59, Sept. 10, 1/5,000 c.c.	Injection of virus No. 59, Sept. 22, 1/5,000 c.c.	Dates of deaths	Remarks
1	5	+	+	Sept. 23	
2	5	+	—	Sept. 17	
3	5	+	—	Sept. 15	
4	10	+	+	Sept. 23	
5	10	+	—	Sept. 14	
6	10	+	+	Sept. 23	
7	15	+	—	Sept. 20	
8	15	+	+	Sept. 23	
9	15	+	—	Sept. 18	
10	—	+	—	Sept. 11	
11	—	+	—	Sept. 11	
12	—	—	+	Sept. 23	
13	—	—	+	Sept. 23	

TABLE 33.

1922 No. 1945

Rabbit No.	Injection of serum No. 1945, March 13, c.c.	Injection of virus No. 59, March 14, 1/10,000c.c.	Injection of virus No. 59, March 29, 1/10,000c.c.	Dates of deaths	Remarks
1	5	+	—	Mar. 15	
2	5	+	—	Mar. 16	
3	5	+	+	.....	
4	10	+	—	Mar. 15	
5	10	+	—	Mar. 15	
6	10	+	—	Mar. 15	
7	15	+	—	Mar. 15	
8	15	+	—	Mar. 15	
9	15	+	—	Mar. 15	
10	—	+	—	Mar. 15	
11	—	+	—	Mar. 15	
12	—	+	—	Mar. 15	

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TABLE 34.

1922 — No. 1946

Rabbit No.	Injection of serum No. 1946, March 13, c.c.	Injection of virus No. 59, March 14, 1/10,000c.c.	Injection of virus No. 59, March 29, 1/10,000c.c.	Dates of deaths	Remarks
1	5	+	+	Mar. 30	
2	5	+	+	Mar. 30	
3	5	+	+	Mar. 30	
4	10	+	+	.....	
5	10	+	+	Mar. 30	
6	10	+	+	Mar. 30	
7	15	+	+	Mar. 30	
8	15	+	—	Mar. 24	
9	15	+	+	Mar. 30	
10	—	+	—	Mar. 16	
11	—	+	—	Mar. 15	
12	—	+	—	Mar. 15	

The results of the serum tests shown by Tables 27-34 are summarized and exhibited in Tables 35-36. It is shown that the variations in the doses were not followed by corresponding differences in the results obtained. It appears that the range between 5 and 15 c.c. is not great enough to show the influence of quantity. The results also show a wide variation in the protective qualities of the sera experimented with. In some the potency was good, in others it was scarcely above that of normal serum. Of the 48 rabbits used in this series, 25 were actually prevented from succumbing to the infection by the use of the serum.

The influence of the serum is further shown by the longer surviving periods of the serum treated rabbits which succumbed as compared with those serving as controls or with those which received normal serum.

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TABLE 35.

Results of virus injections made one day after serum injection of the following doses.

Serum No.	15 c.c.		10 c.c.		5 c.c.		2.5 c.c.		All doses	
	Dead	Alive	Dead	Alive	Dead	Alive	Dead	Alive	Dead	Alive
1053	0	3	0	3	1	2	0	3	1	11
1433	3	0	2	1	3	0	—	—	8	1
1436	2	1	1	2	2	1	—	—	5	4
1945	3	0	3	0	2	1	—	—	8	1
1946	1	2	0	3	0	3	—	—	1	8
Totals	9	6	6	9	8	7	0	3	23	25
Normal 1053	3	0	3	0	3	0	3	0	12	0

Results of virus injections without preceding serum treatment.

Controls belonging to:										
1053	—	—	—	—	—	—	—	—	3	0
1433	—	—	—	—	—	—	—	—	2	0
1436	—	—	—	—	—	—	—	—	2	0
1945	—	—	—	—	—	—	—	—	3	0
1946	—	—	—	—	—	—	—	—	3	0
Totals	—	—	—	—	—	—	—	—	13	0

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Table 36.

Length of surviving periods of animals which died on account of virus injections on the day following serum treatment.

Serum No.	Approximate averages of surviving periods by hours and doses.									
	15 c.c.		10 c.c.		5 c.c.		2.5 c.c.		All doses	
	No. of rabbits	Surviving periods	No. of rabbits	Surviving periods	No. of rabbits	Surviving periods	No. of rabbits	Surviving periods	No. of rabbits	Surviving periods
1053.....	—	—	—	—	1	72	—	—	1	72
1433.....	3	168	2	120	3	152	—	—	8	150
1436.....	2	216	1	96	2	144	—	—	5	163.2
1945.....	3	24	3	24	2	36	—	—	8	27
1946.....	1	240	—	—	—	—	—	—	1	240
Totals and av'gs	9	138.6	6	68	8	111	—	—	23	110.6
Normal 1053.....	3	72	3	72	3	64	3	104	12	69.6
Controls belonging to:										
1053.....	—	—	—	—	—	—	—	—	3	80
1433.....	—	—	—	—	—	—	—	—	2	72
1436.....	—	—	—	—	—	—	—	—	2	24
1945.....	—	—	—	—	—	—	—	—	3	24
1946.....	—	—	—	—	—	—	—	—	3	32
Totals and av'gs	—	—	—	—	—	—	—	—	13	46+

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The 25 rabbits of the above series which survived the first virus injections were again injected with virus some two weeks later. Only two of the lot survived the second injection, and in the ones which succumbed the surviving periods were not materially longer than those shown by the control animals. The results of the second virus injections are shown in Tables 37-38 and they tend to show that the inoculation of a fatal amount of potent virus in a serum-protected animal is not followed by an active immunity of the same.

TABLE 37.

Results of second virus injections in serum-virus treated rabbits.

Serum No.	15 c.c.		10 c.c.		5 c.c.		2.5 c.c.		All doses	
	Dead	Alive	Dead	Alive	Dead	Alive	Dead	Alive	Dead	Alive
1053	3	0	3	0	2	0	3	0	11	0
1433	—	—	1	0	—	—	—	—	1	0
1436	1	0	2	0	1	0	—	—	4	0
1945	—	—	—	—	0	1	—	—	0	1
1946	2	0	2	1	3	0	—	—	7	1
Totals	6	0	8	1	6	1	3	0	23	2
Virus control										
1053	—	—	—	—	—	—	—	—	2	0
1436	—	—	—	—	—	—	—	—	2	0
1945	—	—	—	—	—	—	—	—	2	0
1946	—	—	—	—	—	—	—	—	2	0
Totals	—	—	—	—	—	—	—	—	8	0

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TABLE 38.

Length of surviving periods of animals which were serum-virus treated and which died as a result of a second virus injection.

Serum No.	Approximate averages of surviving periods by doses and in hours							
	15 c.c.		10 c.c.		5 c.c.		All doses	
	No. of rabbits	Surviving periods	No. of rabbits	Surviving periods	No. of rabbits	Surviving periods	No. of rabbits	Surviving periods
1053	3	32	3	32	2	24	8	30
1433	—	—	1	24	—	—	1	24
1436	1	24	2	24	1	24	4	24
1946	2	24	2	24	3	24	7	24
Totals and averages	6	28	8	27	6	24	20	26.4
Virus controls	—	—	—	—	—	—	8	24

In the second part of the experiment with the swine strain sera, all experimental animals received a uniform amount (10 c.c.) of serum and were then divided into groups of which each received a virulent inoculation at periods some three or four days apart. The details of the tests are exhibited in Tables 39-44.

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1921 TABLE 39. No. 1053

Rabbit No.	Injection of serum No. 1053, March 17, c.c.	Injection of virus No. 59, 1/5,000 c.c. Dates	Dates of deaths	Remarks
1	10	March 18	April 8	Death due to injection of 3/10,000 c.c. virus No. 59 on April 7.
2	10	March 18	April 8	Same as above.
3	—	March 18	March 19	Control.
4	—	March 18	March 21	Control.
5	10	March 21	April 9	Death due to injection of 1/5,000 c.c. virus No. 59 on April 7.
6	10	March 21	April 9	Same as above.
7	—	March 21	March 22	Control.
8	—	March 21	March 22	Control.
9	10	March 25	March 27	B. bipolaris in blood.
10	10	March 25	March 29	Many B. bipolaris in blood.
11	—	March 25	March 27	Control.
12	—	March 25	March 26	Control.
13	10	March 28	March 31	B. bipolaris in blood.
14	10	March 28	March 30	Blood swarming with B. bipolaris.
15	—	March 28	March 29	Control.
16	—	March 28	March 29	Control.
17	10	March 31	April 2	Blood swarming with B. bipolaris.
18	10	March 31	April 2	Few B. bipolaris in blood.
19	—	March 31	April 2	Control.
20	—	March 31	April 1	Control.

1921 TABLE 40. No. 1172

Rabbit No.	Injection of serum No. 1172, April 6, c.c.	Injection of virus No. 59, April 17, 1/5,000 c.c.	Injection of virus No. 59, April 23, 1/6,000 c.c.	Dates of deaths	Remarks
1	10	+	+	April 24	
2	10	+	+	April 24	
3	10	+	+	April 24	
4	10	+	+	April 24	
5	10	+	—	April 15	Many B. bipolaris in blood.
6	10	+	+	April 24	

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TABLE 41.

1921 No. 1433

Rabbit No.	Injection of serum No. 1433, Aug. 26, 10 c.c.	Injections of virus No. 59, 1/5,000 c.c.					Dates of deaths	Remarks
		8/31	9/3	9/6	9/9	9/19		
1	+	+	—	—	—	+	Sept. 20	
2	+	+	—	—	—	—	Sept. 9	
3	+	+	—	—	—	—	Sept. 3	
4	—	+	—	—	—	+	Sept. 20	
5	—	+	—	—	—	—	Sept. 1	
6	+	—	+	—	—	+	Sept. 20	
7	+	—	+	—	—	+	Sept. 20	
8	+	—	+	—	—	+	Sept. 20	
9	—	—	+	—	—	+	Sept. 20	
10	—	—	+	—	—	+	Sept. 20	
11	+	—	—	+	—	—	Sept. 7	
12	+	—	—	+	—	—	Sept. 7	
13	+	—	—	+	—	—	Sept. 7	
14	—	—	—	+	—	—	Sept. 8	
15	—	—	—	+	—	—	Sept. 7	
16	+	—	—	—	+	—	Sept. 10	
17	+	—	—	—	+	—	Sept. 10	
18	+	—	—	—	+	—	Sept. 10	
19	—	—	—	—	+	—	Sept. 12	
20	—	—	—	—	+	+	.....	Lived.

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TABLE 42.

1921 No. 1436

Rabbit No.	Injection of serum No. 1436, Sept. 9, 10 c.c.	Injection of virus No. 59, 1/5,000 c.c.				Dates of deaths	Remarks
		9/12	9/15	9/19	9/22		
1	+	+	—	—	—	Sept. 16	
2	+	+	—	—	—	Sept. 17	
3	+	+	—	—	—	Sept. 17	
4	—	+	—	—	—	Sept. 13	
5	—	+	—	—	—	Sept. 13	
6	+	—	+	—	—	Sept. 20	
7	+	—	+	—	—	Sept. 20	
8	+	—	+	—	—	Sept. 17	
9	—	—	+	—	—	Sept. 23	
10	—	—	+	—	—	Sept. 17	
11	+	—	—	+	—	Sept. 20	
12	+	—	—	+	—	Sept. 20	
13	+	—	—	+	—	Sept. 20	
14	—	—	—	+	—	Sept. 21	
15	—	—	—	+	—	Sept. 20	
16	+	—	—	—	+	Sept. 23	
17	+	—	—	—	+	Sept. 23	
18	+	—	—	—	+	Sept. 23	
19	—	—	—	—	+	Sept. 23	
20	—	—	—	—	+	Sept. 23	

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TABLE 43.

1922 No. 1945

Rabbit No.	Injection of serum No. 1945, March 13, 10 c.c.	Injections of virus No. 59, 1/10,000 c.c.							Dates of deaths	Remarks
		3/17	3/21	3/25	3/29	3/31	4/4	4/8		
1	+	+	—	—	—	—	—	—	Mar. 18	
2	+	+	—	—	—	—	—	—	Mar. 19	
3	+	+	—	—	—	—	—	—	Mar. 18	
4	—	+	—	—	—	—	—	—	Mar. 18	
5	—	+	—	—	—	+	—	—	April 1	
6	+	—	+	—	—	—	—	—	Mar. 22	
7	+	—	+	—	—	—	—	—	Mar. 22	
8	+	—	+	—	—	—	—	—	Mar. 22	
9	—	—	+	—	—	—	—	—	Mar. 22	
10	—	—	+	—	—	—	—	—	Mar. 22	
11	+	—	—	+	—	—	—	—	Mar. 26	
12	+	—	—	+	—	—	—	+	April 9	
13	+	—	—	+	—	—	—	—	Mar. 26	
14	—	—	—	+	—	—	—	+	April 9	
15	—	—	—	+	—	—	—	—	Mar. 27	
16	+	—	—	—	+	—	—	—	Mar. 30	
17	+	—	—	—	+	—	—	—	Mar. 30	
18	+	—	—	—	+	—	—	—	Mar. 30	
19	—	—	—	—	+	—	—	—	Mar. 30	
20	—	—	—	—	+	—	—	—	Mar. 30	
21	—	—	—	—	—	+	—	—	April 3	
22	—	—	—	—	—	+	—	—	April 1	
23	—	—	—	—	—	—	+	—	.....	
24	—	—	—	—	—	—	+	—	April 11	
25	—	—	—	—	—	—	—	+	April 9	
26	—	—	—	—	—	—	—	+	April 9	

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TABLE 44.

1922 No. 1946

Rabbit No.	Injection of serum No. 1946, March 13, 10 c.c.	Injections of virus No. 59, 1/10,000 c.c.							Dates of deaths	Remarks
		3/17	3/21	3/25	3/29	3/31	4/4	4/8		
1	+	+	—	—	—	+	—	—	April 1	
2	+	+	—	—	—	+	—	—	April 1	
3	+	+	—	—	—	+	—	—	April 1	
4	—	+	—	—	—	—	—	—	Mar. 18	
5	—	+	—	—	—	—	—	—	Mar. 19	
6	+	—	+	—	—	—	—	—	Mar. 22	
7	+	—	+	—	—	—	+	—	.....	
8	+	—	+	—	—	—	—	—	Mar. 23	
9	—	—	+	—	—	—	—	—	Mar. 22	
10	—	—	+	—	—	—	—	—	Mar. 22	
11	+	—	—	+	—	—	—	—	Mar. 26	
12	+	—	—	+	—	—	—	—	Mar. 26	
13	+	—	—	+	—	—	—	—	Mar. 26	
14	—	—	—	+	—	—	—	+	April 9	
15	—	—	—	+	—	—	—	—	Mar. 26	
16	+	—	—	—	+	—	—	—	Mar. 30	
17	+	—	—	—	+	—	—	—	Mar. 30	
18	+	—	—	—	+	—	—	—	Mar. 30	
19	—	—	—	—	+	—	—	—	Mar. 30	
20	—	—	—	—	+	—	—	—	Mar. 30	
21	—	—	—	—	—	+	—	—	Mar. 31	
22	—	—	—	—	—	+	—	—	April 1	
23	—	—	—	—	—	—	+	—	.....	
24	—	—	—	—	—	—	+	—	April 11	
25	—	—	—	—	—	—	—	+	April 9	
26	—	—	—	—	—	—	—	+	April 9	

The general results of the tests exhibited in the preceding tables are shown in Tables 45 and 46.

It is manifest that in some of the sera examined a striking protective quality is present, but it is also manifest that even in the most potent specimens the passive immunity conferred is of but short duration and that as a rule it has vanished within a week. The influence of the serum is further shown by the lengths of the surviving periods of the animals. It will be observed that as the intervals between serum and virus inoculations lengthen there is a corresponding shortening of the surviving periods. The behavior of the surviving periods is further shown by the graph exhibited in Table 47.

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RESEARCH BULLETIN NO. 22

THE UNIVERSITY OF NEBRASKA

BULLETIN

OF THE

AGRICULTURAL EXPERIMENT STATION

OF

NEBRASKA

A STUDY OF THE ENVIRONMENTAL CONDITIONS INFLUENCING THE DEVELOPMENT OF STEM RUST IN THE ABSENCE OF AN ALTERNATE HOST

I. THE VIABILITY OF THE UREDINIOSPORES OF PUCCINIA GRAMINIS TRITICI FORM III

GEORGE L. PELTIER

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A STUDY OF THE ENVIRONMENTAL CONDITIONS INFLUENCING THE DEVELOPMENT OF STEM RUST IN THE ABSENCE OF AN ALTERNATE HOST[1]

I. THE VIABILITY OF THE UREDINIOSPORES OF PUCCINIA GRAMINIS TRITICI FORM III

GEORGE L. PELTIER

INTRODUCTION

No exact data are at hand regarding the influence of temperature and relative humidity on the viability of the urediniospores of stem rust under controlled conditions. What statements do appear in the literature are general and are of no specific value in that no stated temperature or relative humidity is given. The few chapters devoted to the subject of the viability of the urediniospores by Levine[2] in his review of the literature on "The Epidemiology of Cereal Rusts" may be cited as an illustration of our lack of knowledge on this subject.

In order to determine more accurately the viability of the urediniospores of stem rust of wheat under controlled conditions, a modification of the method developed by the writer[3] in his viability study of *Pseudomonas citri* Hasse was employed. Briefly, this consisted of subjecting uredinia of approximately the same age on detached wheat seedling leaves to various combinations of constant temperatures and relative humidities. At weekly intervals, both germination tests of the urediniospores in the laboratory and infection tests in the greenhouse were made.

APPARATUS USED

Temperature controls.—For temperatures of 25° and 30° C., ordinary bacteriological incubators were employed. For tempera-

[1]Arrangements have been made whereby the publication of the various phases of this project will appear from time to time as Research Bulletins of the Station. Thus, all publications by the author dealing with this project will be issued from one source, so that uniformity in the presentation of the results will be assured.

[2]Levine, M. N. The Epidemiology of Cereal Rusts in General and of the Black Stem Rust in Particular, p. 33-34, 1919. Office of Cereal Investigations, Bureau of Plant Industry, United States Department of Agriculture. Mimeographed.

[3]Peltier, G. L. Influence of Temperature and Humidity on the Growth of *Pseudomonas citri* and its Host Plants and on Infection and Development of the Disease. Jour. Agr. Research 20:488-491, 1920.

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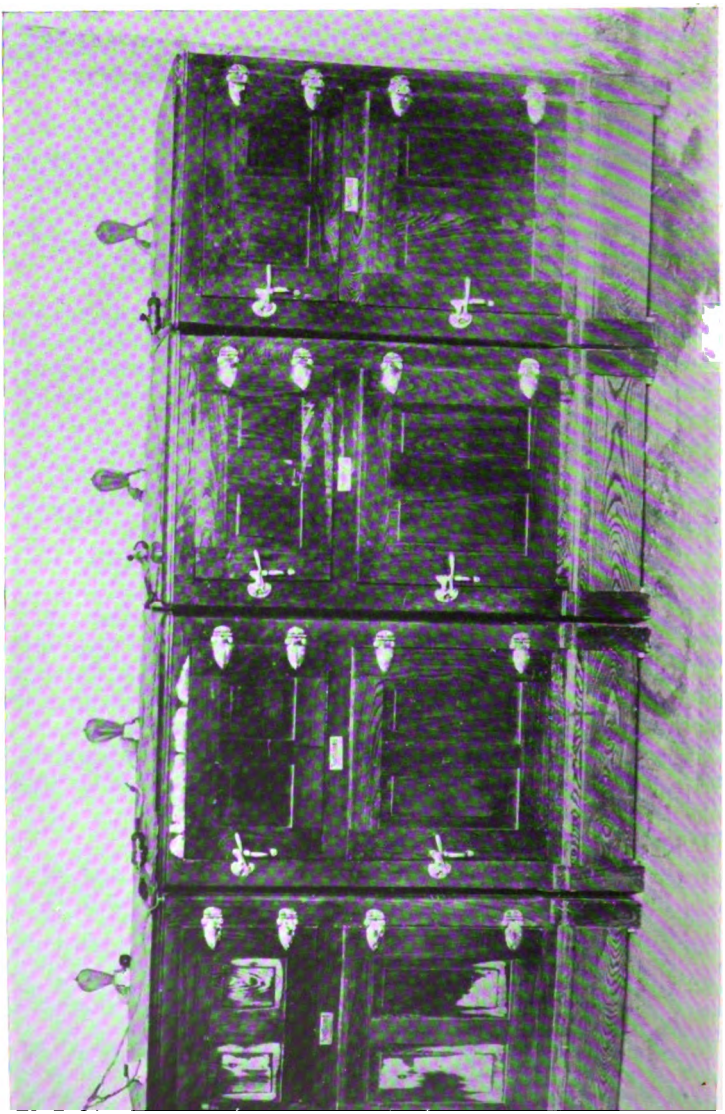

FIG. 1.—Series of incubators in cold storage room.

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tures below 25° C., a highly satisfactory method was devised. Mr. Robert W. Goss, my associate, shares equally in the gradual development of this method of maintaining low temperatures. In developing this method, we went on the principle that it is much easier to maintain constant temperatures in incubators above the temperature of the surrounding medium than it is to maintain temperatures lower than that of the room in which the incubators are kept.

Four two-door ice boxes (14 by 22 by 36 inches, inside measurement) were obtained, the ice compartments dismantled, and two extra shelves put in each box so that the working capacity of the boxes was doubled (fig. 1).

These boxes were equipped with heaters which were made as follows: Chromel wire was wound on two strips of transit and fastened to the underside of a large (12 by 19 in.) transit plate having a row of holes in the center the length of the plate. The whole was then set up from the floor of the boxes (2½ in.) by means of porcelain insulators.

The chromel wire was connected up in parallel. The warm air came up thru the holes in the transit plate and also along the walls of the boxes. In this way a very uniform temperature was maintained thruout the box so that there were no measurable differences between the temperatures on the upper and lower shelves.

For constant temperature controls, the thermostats made by the Chicago Surgical and Electric Company were employed. These were fastened in the center of the back wall of the boxes. The necessary electric connections and pilot lamps completed the equipment (fig. 2).

The incubators were then installed in a cold storage room which was maintained at a more or less constant temperature of 4° C. or slightly below. The thermostats in the incubators were so set that temperatures of 5°, 10°, 15°, and 20° C. were maintained in the respective incubators. In no instance did the temperature in any one of the incubators vary more than one degree either way during the course of the experiment.

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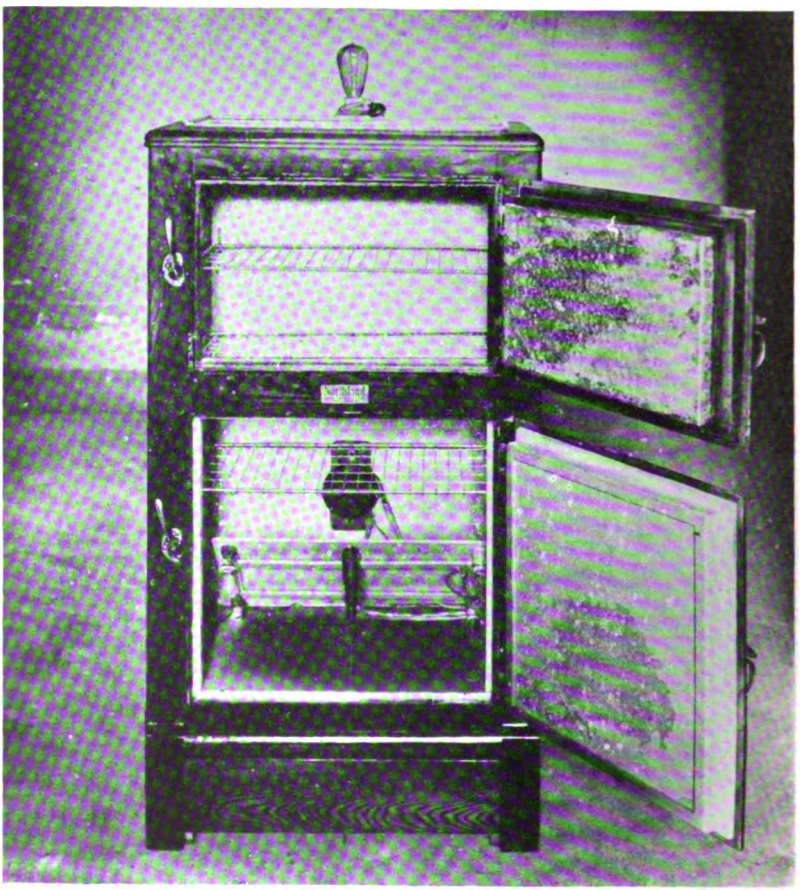

FIG. 2.—Interior of incubator showing heater, thermostat, and shelves.

temperature of this room. We feel sure that this method will solve the low temperature problem for the pathologist, at a cost which is not at all excessive ($50 per box, completely equipped), provided, of course, there is a cold storage plant available.

Humidity controls.—The method used in obtaining the desired relative humidities was essentially the same as that described by the writer[1] in his viability study of *Pseudomonas citri*

[1]*Loc. cit.*

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Hasse. The method pursued in this experiment was as follows: Silk threads were stretched across an aluminum wire frame (B. & S. No. 20) 2⅛ inches square, with legs 1¾ inches high enclosed in glass stockings of the same height. These frames were placed in ordinary preparation dishes, 2 inches high and 3½ inches in diameter with loosely fitting covers resting on a shoulder; and sterilized in the autoclave. These dishes were then filled with the sulfuric acid solution up to the shoulder of the dish so that the threads were about one-fourth of an inch from the liquid. The leaves with rust pustules were placed on these threads.

These dishes were placed in larger Koch moist chambers with ground glass lids, and the solution poured into them until the liquid in both dishes was the same level. The covers of the smaller dishes were then quickly removed and the lids of the outer dishes vaselined and made air-tight (fig. 3).

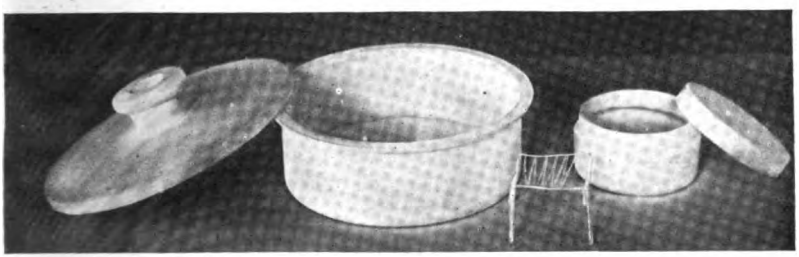

FIG. 3.—Relative humidity chambers, with accessories used in viability experiments.

For the various sulfuric acid concentrations and respective relative humidities, the table published by Stevens[1] was used. The specific gravity of all solutions was determined by a Twadell hydrometer, with the temperature of the solution at 15° C. At the conclusion of the experiment, the solutions were rechecked at the same temperature and in no case was there a variation of more than one or two points on the Twadell scale.

Incubation chambers.—Owing to the large amount of rust material needed for the experiment, and the desirability of maintaining a constant temperature during incubation, the following apparatus was used. The top of a "Wisconsin temperature tank"

[1]Stevens, Neil E. A Method for Studying the Humidity Relations of Fungi in Culture. Phytopathology 6:428-432. 1916.

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was removed together with the cans, a false bottom made of slats placed in the tank about 12 inches below the top, and water brought up to within ¼ or ½ of an inch of this false bottom. By means of a heater with a thermostat connection, the water could be brought to the temperature desired. Over the top of the tank, a large pane of glass was closely fitted. Owing to the large volume of water present, these modified tanks served most admirably for incubation chambers, both from the standpoint of a uniform temperature and from that of the production of a heavy film of water on the leaves. A tank thus fitted up held in the neighborhood of 75 3½-inch pots.

PROCEDURE

On February 1, 1922, about 2,000 Little Club (C. I. No. 4066 from Moccasin, Montana, 1921) wheat seedlings, seven days old, were inoculated with two weeks old material of *Puccinia graminis tritici* Form III, a stock culture of which was kindly furnished the writer by Dr. E. C. Stakman of the Minnesota Agricultural Experiment Station in the fall of 1921. During the season it was transferred each week to Little Club wheat. It may be stated further that it was the only strain of rust introduced into the greenhouse during the season of 1921-1922.

As usual in rust inoculation of wheat seedlings, the plants were trimmed before inoculation and five such trimmed plants were retained in each pot. The plants were sprayed with water by means of an atomizer before inoculation and the wet fingers drawn over leaves just prior to inoculation.

A composite inoculum was obtained by shaking the spores from the pustules on to a glass plate. While the waste of rust material is rather large by this method, it is counterbalanced by the more uniform and higher percentage of successful infections obtained. As Form III was the only rust material present in the greenhouse, no necessity for the sterlization of the flat needle after each inoculation existed. Coupled with the fact that it was not necessary to stop and obtain spores from the pustules on the leaves with the needle at each operation, this greatly facilitated the work. Thus, with an assistant to get the plants ready and place the inoculated plants in the incubation chambers, the writer could inoculate from 2,000 to 2,500 plants in six to eight hours.

The inoculated plants were incubated for 48 hours in the incubation chambers, which were maintained at a constant tem-

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perature of 25° C. At the end of this period the plants were taken out, trimmed, and benched in a greenhouse equipped with a Johnson Service Company temperature control. During the period of 12 days that the plants were benched, the daily mean temperature of the house was 24° C. The plants were trimmed every third day.

Flecking was noted on some of the plants February 5, and by February 7 rust pustules were beginning to appear. On February 14, 13 days after inoculation, the infected leaves were cut off and approximately 30 leaves were placed on the silk threads in each humidity chamber already described.

At the end of each week, one or two leaves, depending on the number of uredinia present per leaf, were withdrawn from each dish. Duplicate germination tests were made. The remainder of the rust material was used for the weekly infection tests in the greenhouse.

A composite sample of the spores from each leaf was germinated in a drop of distilled water placed on a cover glass and inverted over a glass ring, mounted on a glass slide. These were placed in a large, moist chamber and incubated for 24 hours at room temperature. The percentage of germination was determined by counting a total of 200 spores at various points in the microscopic field.

In the greenhouse, five seedling plants were inoculated with the remainder of the rust material from each dish. About 10 or 12 days after inoculation the number of pustules per leaf was recorded.

EXPERIMENTAL DATA

Constant temperatures of 5°, 10°, 15°, 20°, 25°, and 30° C. were used. A set of 11 moist chambers was placed at each temperature, the air in each chamber being maintained at a constant relative humidity by means of sulfuric acid solutions. Thus, at each temperature, there was a series of relative humidities ranging from 0 to 100 per cent, at approximately 10 per cent intervals. The experiment was run over a period of 16 weeks, at the end of which the rust material was exhausted.

Germination tests.—The results of the germination tests are given in Table 1. As none of the urediniospores held at 30° C. germinated, the results are not shown in the table.

No germination of the urediniospores occurred at either the high or the low relative humidities at 25° C. At the medium relative humidities some germination took place, but the percent-

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TABLE 1.—*Viability of the urediniospores of Puccinia graminis tritici Form III.*

Approximate relative humidity	After 1 week	After 2 weeks	After 3 weeks	After 4 weeks	After 5 weeks	After 6 weeks	After 7 weeks	After 8 weeks	After 9 weeks	After 10 weeks	After 11 weeks	After 12 weeks	After 13 weeks	After 14 weeks	After 15 weeks	After 16 weeks
Per cent								*25° C.*								
100.0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
89.9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80.5		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70.4		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60.7		+	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49.0		+	+	—	—	0	0	0	0	0	0	0	0	0	0	0
38.0		0	*	—	0	0	0	0	0	0	0	0	0	0	0	0
29.5		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21.5		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.5		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Per cent								*20° C.*								
100.0	—	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
89.9	*	0	—	0	0	0	0	0	0	0	0	0	0	0	0	0
80.5	—	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70.4	+ +	0	+	0	—	0	0	0	0	0	0	0	0	0	0	0
60.7	+ +	+	+ +	+ +	+	*	—	—	—	0	0	0	0	0	0	0
49.0	+ +	+	+ +	+ +	+ +	+	+	*	—	—	—	—	0	0	0	0
38.0	+ +	+	+	+ +	+	—	—	—	—	0	0	0	0	0	0	0
29.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21.5	+ +	0	—	0	0	0	0	0	0	0	0	0	0	0	0	0
10.5	—	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0	+ +	+	+	0	0	*	—	—	0	0	0	0	0	0	0	0
Per cent								*15° C.*								
100.0	*	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0
89.9	—	0	0	+	0	0	0	0	0	0	0	0	0	0	0	0
80.5	+ +	0	—	—	—	0	0	0	0	0	0	0	0	0	0	0
70.4	—	0	—	—	—	*	0	0	0	0	0	0	0	0	0	0
60.7	+ +	+	+ +	+ +	0	+ +	+ +	+ +	+	—	*	—	—	0	—	0
49.0	+ +	+	+ +	+ +	+ +	+ +	+ +	+ +	+ +	+	—	—	—	0	+	—
38.0	+ +	+	+ +	+ +	+	+	+ +	+ +	0	+	—	—	—	0	—	—
29.5	+ +	+	—	—	0	0	0	0	0	+	0	0	0	0	0	0
21.5	0	0	—	0	0	0	0	0	0	0	0	0	0	0	0	0
10.5	—	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0	+ +	—	+	+	+	+	*	—	0	0	0	0	0	0	0	0
Per cent								*10° C.*								
100.0	*	—	0	—	0	0	0	0	0	0	0	0	0	0	0	0
89.9	*	—	0	*	0	+	*	—	0	—	—	0	0	0	0	0
80.5		+	+ +	+ +	+ +	+	+	+	—	*	—	0	0	0	0	0
70.4	+ +	+ +	+	+	+ +	+	+	+	+	+	*	—	0	*	0	—
60.7	+	—	+	+	+	+ +	+ +	+ +	+ +	+ +	+	—	+	+	—	+
49.0	+ +	+	+ +	+ +	+	+	+ +	+ +	+ +	+ +	+	—	+	+	+	+
38.0	+	+	+ +	—	+ +	+ +	+ +	+ +	—	*	+	—	—	+	—	*
29.5	+	+	+ +	+	0	—	—	—	0	*	+	—	0	+	0	0
21.5	+	*	+ +	*	0	—	0	0	0	*	0	0	0	0	0	0

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age of germination decreased rapidly with an increase of the time interval. At this temperature the maximum length of time that the spores were viable, five weeks, occurred at the relative humidity of 49.0 per cent.

At 20° C., the urediniospores were viable for a greater range of relative humidities and over a longer period than at 25° C. At approximately 100 per cent relative humidity, the spores were viable for one week. A higher percentage of germination over a longer period of time was obtained with each drop in humidity until 49.0 per cent was reached, where the spores were viable at the end of 11 weeks. Again, with each succeeding drop in the relative humidity there was a general decrease in the percentage of spores germinating and they remained viable for a shorter length of time. As at 25° C., the spores gave the highest percentage of germination and were viable longer at the medium humidities.

At 15° C., the urediniospores were viable over longer periods at all humidities than at 20° C. However, there was the same relation between the viability of the spores at the various relative humidities as at 20° C. At the relative humidities of 49.0 to 60.7 per cent the spores germinated at the end of 10 weeks.

At 10° C., the spores gave a higher percentage of germination and were viable for more extended periods at nearly all humidities than at 15° C. At the end of the sixteenth week at the relative humidities of 38.0, 49.0, and 70.4 per cent, a fairly high percentage of spores were still germinating.

At 5° C., the viability of the spores at the medium humidities was still fairly high at the conclusion of the experiment. At the relative humidities above 70.4 per cent, the spores were viable for about as long as the corresponding relative humidities held at 10° C. On the other hand, at relative humidities below 38.0 per cent the spores were viable for a shorter time than at 10° C. These results show that we have reached a point where, at the lower relative humidities held at 5° C., the spores are not as viable as long as at the corresponding relative humidities at 10° C.

If the rust material had been available for further tests, the spores submitted to the medium humidities and temperatures of 5°, 10°, and 15° C. would doubtless have remained viable for a considerable time, as the percentage of germination was still high at the conclusion of the experiment.

It will be noted from the table that in the majority of instances there is a gradual decrease in the percentage of germina-

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tion with an increase in the time interval and that the percentage of germination remains small over a period of several weeks.

Rather peculiar results were obtained at the relative humidity of 10.5 per cent at all temperatures below 25° C. For some unknown reason, a lower percentage of germination was obtained at this point than at the relative humidities of 0 and 21.5 per cent. For example, at 10.5 per cent relative humidity, no spores were found capable of germinating after two weeks at any temperature, while the number of spores germinating at this relative humidity was low in all cases. On the other hand, at the relative humidities of 0 and 21.5 per cent a larger number of spores germinated over a longer period of time, the percentage of germination and the time interval depending somewhat on the temperature at which they were held.

The results of the germination tests show that we have a very definite relation between the viability of urediniospores and the environmental factors of the temperature and relative humidity. No doubt, with the use of a larger number of germination tests and more uniformity of rust material, the results could be expressed in mathematical ratios.

Infection tests.—The purpose of checking up the germination tests with infection tests was twofold. In the first place, it served as a check on the methods used and the results obtained with the germination tests. Further, it afforded an opportunity to determine whether urediniospores still able to germinate were capable of entering the host and producing a pustule.

The results of the infection tests showing the length of time, after being submitted to various temperatures and relative humidities, that the spores were capable of producing infection are given in Table 2.

As a rule the results of the infection tests are in accord with those obtained in the germination tests. In most instances where 10 per cent or more of the spores were viable in the germination tests, infection was successful. There is also a definite relation between the percentage of germination and the number of pustules per leaf and number of leaves infected.

Few or no infections were obtained with any inoculum which showed less than 10 per cent germination. Whether this was due to the small number of viable spores in the inoculum, or whether the spores upon germination were unable to produce infection, is not clear. However, it was observed that as the

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TABLE 2.—*Length of time after being exposed to the various temperatures and relative humidities that the urediniospores of Puccinia graminis tritici Form III were capable of producing infection.*

Approximate relative humidity	25° C.	20° C.	15° C.	10° C.	5° C.
Per cent	*Weeks*	*Weeks*	*Weeks*	*Weeks*	*Weeks*
100.0	0	1	0	1	0
89.9	0	0	0	0	1
80.5	0	1	1	2	2
70.4	0	1	2	16	16
60.7	2	0	14	14	16
49.0	2	1	15	16	16
38.0	0	1	14	14	15
29.5	0	1	1	3	4
21.5	0	0	1	2	4
10.5	0	0	1	0	0
0.0	0	1	1	5	0

percentage of germination decreased from week to week, the germ tubes became shorter, narrower, and the protoplasm was not as dense as in normal germ tubes. Further, when such inoculum was used, hypersensitive flecks were produced on the leaves, indicating that, while the spores were capable of germinating and sending a germ tube into the tissues, the resistance offered by the host cells was greater than the fungus could overcome. Judging from the data obtained, we can assume that a point is reached where the urediniospores are so attenuated under certain environmental conditions that while they are still able to germinate they are unable to produce infection.

DISCUSSION

The problem of the viability of the urediniospores of stem rust under field conditions is a question of their ability to overwinter in the North or oversummer in the South. The consensus of opinion is that the urediniospores of *Puccinia graminis tritici* do not overwinter in the North. This is borne out by the results obtained by the writer during the past two winters in field experiments conducted at Lincoln. Rust epidemics were started in the fall and urediniospores were found that germinated readily as far into the winter as January, but after this time it was exceedingly

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difficult to find urediniospores, and what few were found did not germinate.

Infections in the late fall on winter wheat are usually confined to the lower and outer leaves and these are the first leaves which dry up under adverse environmental conditions. Thus, the use of detached leaves in the experiment reported was the nearest approach possible, under artificial conditions, to what actually occurs in the field. The results, while they do not touch the whole of the overwintering question, do show that down to certain temperatures the urediniospores are viable for long periods of time at the prevailing relative humidities encountered in the field in the fall in the winter wheat belt. Experiments will be carried out this coming year with temperatures below freezing. The effect of alternate freezing and thawing on the viability of urediniospores will also be determined.

The results show clearly that at constant temperatures below the mean temperatures prevailing during the summer months in the South the urediniospores are not viable for any great length of time at any relative humidity. At first thought one would say that the results show that oversummering could not take place in the South. Further, the mean temperatures prevalent in the South during the summer months are near the maximum at which germination of the urediniospores can take place. Where, then, do the urediniospores that produce infection in the fall on winter wheat in the South come from?

The mortality of the free urediniospores must be extremely high at all times. The rate of mortality would naturally vary with the environmental factors encountered. Further, a definite set of conditions must be at hand for infection to take place. These conditions are not always present, so that the death rate of the viable spores would further be increased. Thus, it is safe to assume that only a small proportion of the countless number of urediniospores produced actually infect the host, except during the short periods when the conditions for successful infection are at hand.

It should be distinctly understood that the generalizations offered above are based on the results obtained with only one biologic form. Will other biologic forms of stem rust react in the same way, or will they behave differently to stated temperatures and relative humidities by having a lower or higher percentage of germination and a shorter or longer period of viability? To determine these points, it is the purpose of the writer to continue this work with other biologic forms of stem rust.

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CONCLUSIONS

1. The influence of relative humidity on the viability of the urediniospores of *Puccinia graminis tritici* Form III is very pronounced and closely associated with temperature.

2. At high relative humidities, depending somewhat on the temperature, the percentage of germination is low and the period over which the spores are viable is very short.

3. The same relation exists at the low relative humidities except that it is not so pronounced and is more variable.

4. The highest percentage of germination and the longest viable period of the spores occur at the medium relative humidities. High temperatures lower the percentage of germination and shorten the viable period while at low temperatures the opposite occurs, at the medium relative humidities.

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Relation of Environment and Other Factors to Potato Wilt Caused by Fusarium Oxysporum

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SUMMARY

1.—*Fusarium oxysporum* is a soil saprophyte capable of parasitizing the potato plant under conditions favorable for the growth of the organism, and the action of the disease after infection has taken place is accelerated by conditions unfavorable for the host.

2.—There are three methods of infection of potato plants with *Fusarium oxysporium* 1st, infection from the soil thru the seed tuber, 2nd, from the soil thru the roots and stem, and 3rd, infection from the seed tuber.

3.—The initial infection is largely influenced by environmental conditions, and the environmental conditions may also cause a considerable change in the latter symptoms of the disease.

4.—The complexity of environmental factors influencing the disease results in many inconclusive results from inoculation experiments and increases the difficulty of interpreting the behavior of the disease in the field.

5.—It was found impossible to consistently reproduce the disease under any of the conditions and with any of the methods used in these experiments.

6.—Growth-temperature studies of *Fusarium oxysporum* in pure culture show that different strains of this species vary in their optimum temperature for growth at least 5°C. These differences were more marked in liquid cultures than in petri dish cultures. It was also shown that by the use of different liquid media it was possible to cause a lowering of 5°-10° in the optimum temperature for growth.

7.—Pathogenicity tests of growing plants showed that the potato plant is more susceptible to infection during its early growth.

8.—The host plant may often be infected without the symptoms of the disease appearing, under conditions favorable for the plant.

9.—A discoloration of the vascular system of both stem and tubers in the absence of any causal organism is often produced under conditions of high temperature and low soil moisture.

10.—Soil infection experiments with pure cultures of the organism under a wide range of conditions in which the

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small percentage of infection. The results, however, clearly indicated that temperatures of 18°C. and below are very unfavorable for the development of the disease and that the amount of infection increases with increasing soil temperatures. The disease develops most rapidly when the temperatures are too high for vigorous growth of the host plant. Plants started at a temperature of 18° and later changed to higher temperatures showed as much disease as those kept at a constant high temperature. Plants started at a high temperature and later transferred to low temperatures showed practically no disease symptoms even tho the organism was present in small amounts in the finer rootlets.

11.—Constant low soil moisture is unfavorable for infection. After plants have become infected a lowering of the soil moisture accelerates the wilting of the plant.

12.—With increasing soil moistures the amount of rotting of the stems and roots of infected plants increases and the wilting symptoms are not as marked.

13.—In all the infection experiments with inoculated soil, infection took place thru the roots rather than thru the seed-piece.

14.—Field experiments with seed inoculations under three different environmental conditions showed that the greatest amount of disease developed in the plot having low soil temperatures during the early period of growth with a decreasing soil moisture content and increasing soil temperatures in the latter part of the experiment. With conditions very similar except for the application of two irrigations during the latter stages of growth, a small amount of disease developed but the plants were more vigorous. In another plot with the same general type of temperature and moisture curve as in the one showing the greatest amount of disease, but with much higher temperatures and higher soil moistures thruout the experiment, practically no disease developed.

15.—Infection from the soil was found to be the prevalent method of infection in Michigan and Nebraska. Such infection was usually thru the roots rather than thru the seed-piece.

16.—Only a small per cent of tubers having vascular discoloration contain *Fusarium oxysporum* and these tubers do not usually reproduce the disease except under conditions very favorable for this type of infection.

17.—Neither vascular discoloration of the tuber nor of the stem is a good index of infection with *Fusarium oxysporum* unless

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these symptoms are found in connection with a wilted plant. Vascular discoloration can be produced in the absence of any organism and can often be correlated in the field with high soil temperatures combined with drought.

18.—Control of the disease by cutting away the discolored portion of seed tubers is not practicable.

19.—Seed tubers showing vascular discoloration, while they usually do not reproduce the disease directly, do produce weak plants that are easily infected from the soil. Such tubers should not be used for seed purposes.

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Relation of Environment and Other Factors to Potato Wilt Caused by Fusarium Oxysporum[1]

R. W. Goss

INTRODUCTION

It has been generally accepted by plant pathologists that *Fusarium oxysporum* Schlect. is a very active pathogene causing one of the most widespread and serious diseases of the potato, commonly known as Fusarium wilt or blight. This opinion, however, has been based chiefly upon observations rather than upon conclusive experimental evidence. Many of these observations relating to the widespread activity and seriousness of the disease have been based upon data which have since been proved to be a poor criterion in judging the amount of disease.

A critical review of the literature shows that much of the experimental evidence is either incomplete or negative. Many of the inoculation experiments reported by various investigators were unsuccessful. Results from repetition of the same experiments were often contradictory, and there has been a general failure to reproduce the disease as it occurs in the field. Certain types of the disease have been produced while other types have never been produced experimentally. In most of the inoculation experiments reported in the literature, the methods used have been very drastic and even then a rather low percentage of infected plants has been obtained. The evidence presented does not justify many of the widely drawn conclusions as to the extremely active pathogenic nature of *Fusarium oxysporum*, but rather points out a lack of knowledge of the influence of various factors upon the occurrence of the disease.

In studying potato wilt caused by *Fusarium oxysporum* under widely divergent conditions, it appeared to the writer that there were three probable methods of infection:

1. From the soil thru the seed tuber.
2. From the soil thru the roots and stems.
3. From seed tubers having internal infection.

These three types of infection would be influenced largely by the following factors: 1. Soil temperature. 2. Soil moisture.

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3. Pathogenicity of the strain of *Fusarium oxysporum* present.
4. Temperature differences with different strains of *F. oxysporum*.
5. Differences in susceptibility of the potatoes, both individual and varietal. The disease would also be influenced more indirectly by atmospheric temperature, relative humidity, sunshine, and other factors influencing the development of the host.

This complexity of factors tends to produce uncertain or inconclusive results in experimental work and increases the difficulty of interpreting the behavior of the disease in the field.

The present work was undertaken to determine the influence of some of these environmental factors on the infection and progress of the disease. The work has not progressed to the point of determining the exact relation of each of these chief factors. However, the results thus far obtained are presented here in order to direct attention to the nature and distribution of the disease in relation to the environmental condtions under which certain types of infection take place.

PREVALENCE AND LOSS

It is impossible to determine accurately the actual loss in yield due to *Fusarium oxysporum*. The nature of the disease is such that an estimate of the loss in commercial fields is a matter of guesswork rather than of accurately compiled data. It is true of this disease, as of many others, that the estimated losses are often exaggerated, owing to confusion with other troubles, and to the fact that actual losses in yields cannot be accurately estimated except in experimental plots or in cases of epidemics.

The distribution of the disease is widespread, as the organism is almost universally present in the soil. Pratt (1916)[1] found that disease-free tubers planted on virgin desert soil in Idaho produced 29.3 per cent vascular infection as determined by pure cultures. Werkenthin (1916) found *Fusarium oxysporum* to be present in virgin soils of Texas. The writer has isolated the organism from virgin forest soils in the upper peninsula of

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Year	Loss per state Per cent	No. states with 10 per cent loss	No. states with 5 per cent loss
1918	2.3	5	14
1919	1.6	2	7
1920	1.6	2	4

In the six leading states in potato production for these three years, the highest reported losses are 6 and 5 per cent in 1918. In 1919 and 1920 none of these states report more than 3 per cent loss.

Many estimates of the amount of infection have been based upon vascular discoloration rather than upon the number of wilted plants in the field, altho we are now aware that vascular discoloration is not a true index of the presence of *Fusarium oxysporum*.

In 1914, 100 fields in Michigan being grown for seed purposes were inspected by the author. The amount of disease was estimated both by counts of the number of wilted plants and by digging up 4 or 5 lots of 10 hills each in every field and examining for vascular discoloration. Twenty-one per cent of the fields showed Fusarium wilt as evidenced by actual wilting; only one of these fields showed more than 10 per cent infection, and the average amount of infection was 1.5 per cent. If the vascular browning of stems or tubers had been used as an indication of disease, it would have been found that out of the 100 fields inspected, 96 showed plants with discolored vascular systems, averaging 30 per cent infection per field.

In Nebraska, in 1920, the author examined about 900 acres and found about 82 per cent of the fields infected with wilt, averaging 6 per cent infection. In 1921 as a result of the seed certification work carried on by the Horticultural Department of the University of Nebraska, 83 per cent of the acreage inspected was found to contain wilt averaging about 3 per cent infection. These estimates in Nebraska also include a considerable amount of wilt due to causes other than *Fusarium oxysporum*, so that the actual damage due to this one organism is considerably less than the above reports would indicate.

Judging from the results of a number of surveys made in different states, the author considers Fusarium wilt to be a widespread disease which in some sections may produce considerable injury over limited areas but is usually not serious over entire states. The wide variations in the amount of infection in some states over a period of years indicate that environmental conditions play an important role in determining the severity of the attack. The amount of infection in the same fields in successive

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years will vary widely, irrespective of the potatoes planted or treatment of either soil or seed.

SOURCE OF CULTURES

The various strains of *Fusarium oxysporum* used in all the following experiments are listed below with their origin.

Strain No. 1.—Isolated by the author from the discolored vascular bundles of a potato tuber in Michigan, October 15, 1914. This culture was identified by H. W. Wollenweber and numbered 3377 by the United States Department of Agriculture.

Strain No. 8.—Culture obtained from C. W. Carpenter of the United States Department of Agriculture as No. 3395.

Strain No. 32.—Culture obtained from G. K. K. Link of the University of Nebraska as No. 3345a, and obtained by him from the United States Department of Agriculture.

Strain No. 33.—Culture received by James Johnson of the University of Wisconsin from W. G. Gilbert, United States Department of Agriculture as No. II.

Strain No. 35.—Reisolation of Strain No. 33 made in 1920 from inoculated plants showing wilt.

Strain No. 56.—Reisolation of Strain No. 33 made in 1921 from the roots of inoculated plants.

While these strains were of greatly different ages, no differences could be observed in any of the inoculation experiments indicating a loss in virulence due to the age of the culture.

GROWTH-TEMPERATURE RELATIONS OF FUSARIUM OXYSPORUM IN PURE CULTURE

In studying the relation of temperature to the infection and progress of the disease it was also deemed advisable to determine the effect of temperature on the growth of the organism in pure culture. While such a study does not necessarily give a true index of disease phenomena under natural conditions, it does aid materially in interpreting the action of the disease both in the field

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In reviewing the literature on the subject it was found that in all the experiments reported it was assumed that different strains of *Fusarium oxysporum* would react similarly to the same temperature conditions; that is, while the total growth might vary, the cardinal points for growth would remain the same. It was also assumed that the same effect upon the growth-temperature relations would be true of the use of different media.

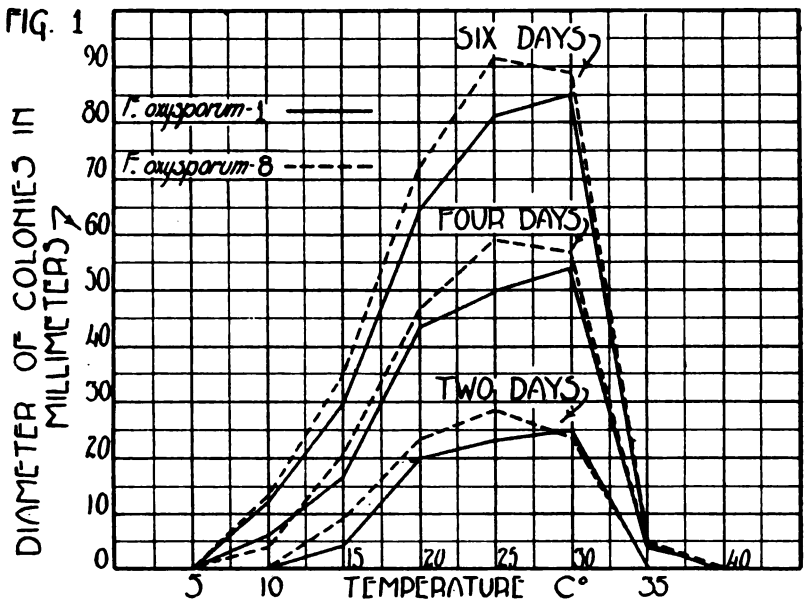

FIG. 1.—Graph showing the rate of growth of 2 strains of *Fusarium oxysporum* on potato agar at different temperatures.

Preliminary experiments conducted by the writer indicated that different strains react differently to temperature effects. The media used were also found to cause a shifting of the cardinal points for growth. Further experiments were therefore conducted with a number of strains of *Fusarium oxysporum* and with several other species of Fusarium. These tests were made on various media both solid and liquid.[1] While lack of space will not permit the publication of the detailed experiments at this time, typical examples of some of the results are presented here.

In test tube cultures of Strains Nos. 1, 8, and 32 on potato plugs, submitted to temperatures between 5° and 38° at about 2° intervals, it was found that growth occurred at 9.5° but not at 7°; growth also occurred at 37.5° but not at 38°C. The

[1] These results are being published as a separate paper.

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optimum temperature for growth was between 24° and 28°. No differences in the reaction of the different strains to temperature were noted.

In petri dish cultures on hard potato agar it was found that different strains produced their maximum growth at different temperatures. In these cultures the daily increase in the diameter of the colony was used as the index of growth. Figure 1 shows the comparative results of 2 strains of *Fusarium oxysporum*. It is evident that one strain shows greater growth at the lower temperatures and its maximum growth is produced at a point 5°C. lower than the other strain. The difference was found in all trials and in all media, being even more marked in liquid media.

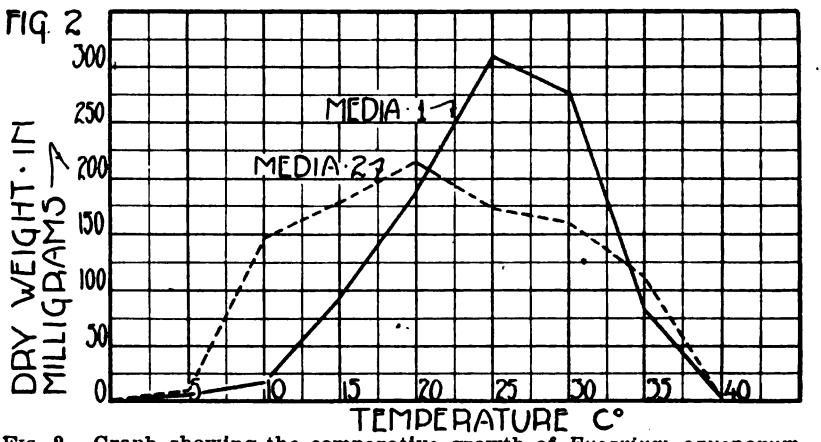

FIG. 2.—Graph showing the comparative growth of *Fusarium oxysporum*, after 3 weeks on 2 different liquid media.

In tests with liquid media, determining the growth by dry weights, it was also found that the use of different nutrient solutions resulted in a shifting of the minima, optima, and maxima temperatures for growth. Figure 2 shows the average results of 4 trials with *Fusarium oxysporum* No. 32. In these tests the 2 media used were made up as follows:

Media No. 1		Media No. 2	
125 c.c.	M/1 NH_4NO_3	20 gm.	NH_4NO_3
50 c.c.	M/1 KH_2PO_4	10 gm.	KH_2PO_4
20 c.c.	M/1 Mg SO_4	5 gm.	Mg SO_4
150 c.c.	M/1 Sucrose	500 c.c.	Potato extract from 500 gm. of potatoes.
1 c.c.	M/1000 Fe Cl_3		
654 c.c.	Distilled water	500 c.c.	Water
1000 c.c.		1000 c.c.	

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It is evident that these 2 media cause a considerable difference in the reaction of the same organisms to different temperatures. In Media No. 2 there is a shifting of the optimum temperature for growth 5°C. below that for Media No. 1. There is also a greater growth at the suboptimal temperatures and less growth in the supraoptimal region. This difference was also found with a number of other strains and species.

In liquid media it was also possible to obtain weighable growth at 5°C., while in petri dish cultures no growth was observed at this temperature.

These data explain to some extent the different results reported by various investigators. They also show that in inoculation experiments with controlled temperatures the manifestation of the disease at certain temperatures may depend partially at least upon the strain of organism being studied.

INFECTION EXPERIMENTS

It has always been recognized that Fusarium wilt is very greatly influenced by environmental conditions, chiefly by the temperature and moisture of both soil and air. Just how great a part these factors play in determining the infection and progress of the disease has not previously been determined experimentally.

In the following work presented in this paper an attempt has been made to study this disease with various factors under control. The chief difficulties lie in the fact that at present we must of necessity work with maintained conditions rather than with the fluctuating conditions found in nature. The number of individuals in each test is very small under the best experimental conditions and our knowledge of the reactions of the host to the various environmental conditions even in the absence of disease is fragmentary. The results, as to the effect of the various environmental factors, are presented separately for the different types of infection.

Pathogenicity Tests By Direct Inoculation of Growing Plants

Altho it has been generally accepted that *Fusarium oxysporum* is the causal organism producing the wilt of the potato vine, until recent years there have been practically no inoculation experiments reported, and even in the few experiments reported the results have often been inconclusive.

REVIEW

Smith and Swingle (1904) isolated the organism and described the disease, but no inoculation experiments were reported.

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Manns (1911) reported inoculation experiments but he does not give any detail experiments with pure cultures. He states (p. 316):

> Artificial infections were brought about in a number of ways. Slight injuries of the roots or knife incisions in the presence of the organism brought about the most rapid infections. The organism is, however, productive of infection in the absence of any root disturbance or stem injury, as was shown by a number of experiments.

Link (1916) reports experimental infections of living plants with *Fusarium oxysporum*. He obtained his largest percentage of infections by smearing the sprouts with rice cultures of the organism as they were just breaking thru the ground. By using inoculated soil he obtained variable results and suggests that this may have been due to a loss in vitality of the organism, or to a gain in the resistance of the plant as the season progressed. Sherbakoff (1915) reports that he was unable to obtain positive infection with cultures of *F. oxysporum*. He suggests that this may have been due to a loss in virulence of the cultures.

These few reported experiments with direct inoculations of growing plants have certainly not produced any very definite or conclusive evidence that *Fusarium oxysporum* is a very active wilt parasite. The inoculations while very drastic in their nature, did not always yield uniform results. The evidence indicates that the organism, instead of being a very active parasite, is rather a weak one and that it is probably greatly influenced by conditions that were not kept under control in these tests.

EXPERIMENTAL DATA

The following infection experiments relate only to artificial inoculations of stems and roots, somewhat similar to those reviewed above.

Methods.—In the following experiments only vigorous plants grown from healthy seed were used. The tubers were examined for the absence of any vascular browning, treated with mercuric chloride and planted in sterilized soil. In all cases unless otherwise stated, the stems were inoculated by removing the soil from around the stem, which was then disinfected, and a small wound made with a sterilized scalpel just below the surface of the ground. A small amount of the inoculum was then introduced into the wound and the soil packed back in position and a little sterile water added.

Greenhouse Experiments

EXPERIMENT 1, MARCH, 1916

Plants of the Rural New Yorker variety growing in the greenhouse were inoculated at different ages with different strains of *Fusarium oxysporum* in an attempt to observe any differences in the virulence of the strains or any indications of the plants showing different degrees of resistance as they became older.

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Set 1. Three plants were inoculated when 2 to 5 inches in height with *Fusarium oxysporum* No. 1, grown on steamed potato cylinders. Plant 1 showed typical wilt and heavy infection throughout the vascular system. In plant 2 the mycelium of the fungus could be seen penetrating the vascular system of the stem for a short distance from the point of inoculation; no wilting occurred in this case. Plant 3 remained healthy.

Set 2. Three plants were inoculated at the same age as those in Set 1 with *Fusarium oxysporum* No. 8. Plant 1 showed a heavy infection and early wilting. Plants 2 and 3 showed only a slight penetration of the host and did not wilt.

Set 3. Three plants 5 to 10 inches in height were inoculated with *Fusarium oxysporum* No. 1. None of these plants showed any symptoms of wilt and only in 2 instances was there a slight penetration of the host from the point of inoculation.

Set 4. Three plants 5 to 10 inches in height were inoculated with *Fusarium oxysporum* No. 8. No wilting occurred. All plants showed a slight vascular discoloration for about 1 inch from the point of inoculation.

Set 5. Six plants used as controls remained healthy except in one instance where a wilting of the tops occurred and from which *Fusarium oxysporum* was isolated.

These few tests do not show consistent results, but do indicate that the inoculation of younger plants will give a higher percentage of infection. There was no apparent difference in the 2 strains of *Fusarium oxysporum* used.

EXPERIMENT 2, MARCH, 1917

Four plants of the Rural New Yorker variety growing in the greenhouse were inoculated, just as the shoots were showing at the surface of the ground, with *Fusarium oxysporum* No. 8. All 4 of these remained healthy.

The previous test was repeated. Seed from the same source was used and inoculations were made with the same strain of *Fusarium oxysporum* just as the sprouts broke thru the ground. Three of these plants showed early signs of wilt. The fungus was present abundantly in the vascular tissue, and was recovered in every instance in pure culture. One plant remained healthy. All control plants remained healthy.

EXPERIMENT 3, FEBRUARY 21, 1920

This experiment was conducted at two different temperatures, half of the plants being placed in a greenhouse maintained at 17°, and half in another house at 27°C. In each house 5 plants were inoculated when they were 10 days old and 4 others were used as controls. Some of the plants at each temperature were inoculated with *Fusarium oxysporum* No. 33, and some with No. 8.

Results.—17°C. The plants were all examined May 6. Two plants were inoculated with *Fusarium oxysporum* No. 33. One stem of plant 1 was inoculated; there was no infection and the wound calloused over; 4 control stems remained healthy. One stem of plant 2 was inoculated, no wilt resulted, the wound calloused over and there was a slight penetration of the vascular system for ¼ inch beyond wound; 2 control stems remained healthy. Three plants were inoculated with *Fusarium oxy-*

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sporum No. 8. All wounds healed over and there was no infection or sign of wilt. All controls remained healthy.

Results.—27°C. Four plants were inoculated with *Fusarium oxysporum* No. 33. Three stems of plant 1 were inoculated; the tops wilted slightly, the wound on the stem healed over and there were diffuse light brown lesions around the stem but no rotting. Sections of the stem showed invasion of the vascular system and browning extending ¾ inch above the wound. *F. oxysporum* was recovered from the vascular system. Plant 2 remained healthy; the wound healed over, and there were no lesions or browning of the vascular system. Infection did not progress beyond the wound. Two stems of plant 3 were inoculated, there was no wilt but the organism invaded the vascular system for 1 inch above the wound and below as far as the roots. No external lesions were present. *F. oxysporum* was recovered. Three stems of plant 4 were inoculated. One stem with healthy tops showed a slight invasion of the tissue around the wound, while 2 other stems with the tops completely wilted had the underground stem entirely rotted below the wound. One plant was inoculated with Strain No. 8. There was no infection; the entire plant remained healthy, and the wound healed over. The controls remained healthy.

EXPERIMENT 4, 1921-22

During the winter of 1921-22 a few inoculations were made on plants in the greenhouse. Tubers of the Bliss Triumph variety were planted in tuber units; 1 plant was used as a control and 3 others were inoculated, both by stem inoculations and by pouring a water suspension of spores on the soil at the same time. The plants were inoculated when they were 6 to 8 inches high.

Three inoculated plants and 1 control were kept in a glass incubating chamber where the soil and air temperature was kept between 30° and 36°C. The other set of 4 plants was kept at a temperature of about 24°. The plants were dug and examined 6 weeks after inoculation. In the set at 30° to 36°, plant 1 had 1 stem entirely dead and the other slightly yellowed. Plant 2 was entirely dead, apparently due to temperature. Plant 3 wilted completely. The control plant was also completely wilted. In the set at 21° to 26° all plants showed a slight yellowing of the foliage; there was no complete wilt and no discoloration of the vascular system. The control plant remained healthy.

EXPERIMENT 5, DECEMBER, 1921

Inoculation tests with other organisms to determine the relative values of the methods of inoculation were made in 1921. Cultures of *Penicillium* sp. and *Rhizopus* sp. were used in order to test whether the methods generally used in determining the parasitism of *Fusarium oxysporum* are so drastic that even very weak parasites would be able to produce similar symptoms.

Potato plants of the Bliss Triumph variety grown in the greenhouse at about 24°C. were inoculated either by smearing the emerging sprout or by inserting into the stem portions of agar cultures of the organisms to be tested. The plants were dug up and examined one month after being inoculated.

Results.—No wilting occurred in any of the plants. Plants inoculated with *Penicillium* sp. or *Rhizopus* sp. by smearing the emerging sprout remained healthy and the organisms did not penetrate the host

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tissue. When the sprouts were wounded and the inoculum inserted it was found that both organisms had penetrated from ¼ to 1½ inches beyond the point of inoculation. The vascular tissue was discolored, but the infection was not entirely confined to vascular tissue. *Rhizopus* sp. was able to cause considerable more rotting than *Penicillium* sp. and produced symptoms very similar to those found in the inoculations with *Fusarium oxysporum.*

Field Experiments

EXPERIMENT 1, 1916

Methods.—Inoculation experiments with pure cultures were made on a large scale in the field in the summer of 1916 in Michigan. Potato plants of the Rural New Yorker variety grown from healthy seed were used for this experiment. Some of these plants were inoculated as soon as the sprouts showed thru the ground, others when they were 5 to 6 inches high. Inoculations were made either by introducing the organism into the stem just below the surface of the ground or by soil inoculation both with and without wounding the roots. The inoculum was obtained from 10-day-old potato plug cultures of *Fusarium oxysporum*, also with three varieties of *F. oxysporum* obtained in 1915 from C. D. Sherbakoff at Cornell University. Altogether, about 1,000 plants were inoculated. The tubers were planted June 14 and 15, the sprouts were inoculated the last week in June, and the final results taken at digging time, September 10.

During the experiment air temperature records were taken by means of a thermograph placed in a shelter in the center of the field. Soil temperature records were taken with maximum and minimum thermometers placed in the soil at the depth of 5 inches and readings taken every 24 hours. After August 15, a soil thermograph was used. Precipitation records were obtained from the United States Weather Bureau located about one mile away, and these give a fair indication of the moisture content.

The air temperature was very high during the months of July and August. The mean maximum temperature for July was 91.8° (33.2° C.) and for August 84.9° F. (29.4° C.). The mean average temperature for July was 71.1° (21.7° C.) and for August 72.7° (22.6° C.). The highest recorded temperature was 104° (40° C.) the 29th of August. It is worthy of notice that from the 20th of July to the 7th of August the lowest maximum temperature was 92° (33.3° C.). The soil temperature from July 20 to August 15 showed a mean maximum of 104° (40° C.) and a mean minimum of 63° (17.2° C.). The highest temperature, 111° (43.9° C.), was reached a number of times and was the highest that the only available thermometers at the time would record. Undoubtedly the temperature went higher than this on a number of days. After August 15, the soil temperature dropped considerably, owing to an increase in the rainfall. The total precipitation for July was only .09 inch and for August 1.58 inches.

Results.—No typical wilting occurred in any of the thousand-odd plants inoculated. Each hill was examined for infection by cutting sections thru the root and tubers, and also thru the stem. More than 90 per cent of the inoculated plants were found to have a slight browning of the vascular system, and the controls contained a similar amount. A large number of cultures were made in the laboratory in an attempt to isolate the organism from these discolored vascular areas, but without exception they were unsuccessful.

The combination of very low precipitation and very high

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temperature during this experiment produced an environmental condition very unfavorable for the growth of the potato. Furthermore, these conditions were also unfavorable for infection by *Fusarium oxysporum* even tho Fusarium wilt is usually considered a warm weather disease. It is evident that the low soil moisture content was not favorable for initial infection and therefore high temperatures combined with low moisture have no influence on the disease unless the moisture content has previously been high enough to permit the initial penetration by the causal organism.

EXPERIMENT 2, 1921

During the summer of 1921 a few inoculations of growing plants were made in the experimental potato fields at Lincoln and Mitchell,[1] Nebraska. In the Mitchell fields the experiments were conducted under both dry land and irrigated conditions. The air and soil temperature and moisture records are shown in Figures 3, 4, and 5. Healthy tubers of the Bliss Triumph variety planted in tuber units were used for these tests.

Plot 1, Lincoln.—Tubers were planted June 4 and were inoculated June 25. Stem inoculations were made the same as in previous experiments, every stem in each hill being inoculated. The plants were 4 to 5 inches high at the time of inoculation. Four plants were inoculated with *Fusarium oxysporum* No. 1, 4 with No. 8, 6 with No. 35, and 8 with No. 56. One hill in each tuber unit was used as a control.

Results.—None of the plants at any time showed symptoms of wilting. Both inoculated and control plants were small and considerably dwarfed, due to the high temperature of both soil and air. The plants were dug September 2. All inoculated plants showed a browning of the vascular system from the point of inoculation to the base of the stem, while the control plants remained healthy.

Plot 2, Dry Land, Mitchell.—The tubers were planted May 20. Inoculations were made June 17, when the plants were from 1 to 6 inches in height. Stem inoculations were made in the same way as the previous experiments. Five plants were inoculated with *Fusarium oxysporum* No. 35 and 5 with No. 56.

Results.—On August 16 one plant inoculated with Strain No. 35 showed typical Fusarium wilt. All other inoculated plants and controls remained healthy. These plants were dug September 21. Of the 4 remaining plants inoculated with No. 35, 1 was perfectly healthy and 3 showed a browning of the vascular system of the stem. One of these 3 produced tubers showing vascular browning. Of the 5 plants inoculated with No. 56, 2 remained healthy. One plant showed vascular browning of the stem and produced 1 tuber out of 6 showing vascular browning.

Plot 3, Irrigation, Mitchell.—Tubers of the same lot as those in Plot 2 were planted and inoculated at the same time. The plants averaged about 4 inches in height when inoculated. Six plants were inoculated with *Fusarium oxysporum* No. 35 and 6 with No. 56.

Results.—No wilting occurred in any of the 12 inoculated plants, altho when dug September 21, practically every stem showed considerable

[1] Scotts Bluff Substation, located at Mitchell, Nebraska.

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vascular browning; no rotting of the stem was present and no infected tubers were produced.

DISCUSSION

These preliminary tests of the pathogenicity of *Fusarium oxysporum* made in a similar way to those reported in various papers on this disease show very clearly that consistent results are not obtained by these methods even tho the methods of inoculation are drastic enough to permit similar symptoms to appear when inoculations are made with relatively weak parasites. The large number of negative results indicates clearly that *F. oxysporum* is not a very virulent or a very destructive organism. These tests also show that the plant is more susceptible to infection during the early growth. It is also shown that considerable tissue may be infected and the vascular system distinctly discolored without any symptoms of wilt appearing on the plant. The experiments in the greenhouse indicated that high temperatures favor the development of the disease. However, the field experiments conducted in 1916 show clearly that an extremely high temperature and a very low soil moisture content produce conditions unfavorable for infection. Under these conditions a discoloration of the vascular system occurs that is not connected in any way with the disease.

TRANSMISSION OF FUSARIUM WILT BY INFECTED SEED

Review of the Literature

VASCULAR DISCOLORATION OF TUBERS

Until very recently it has been commonly believed, as evidenced by the oft repeated assertions found in bulletins, circulars, and in practically all the information given to the farmers relative to Fusarium wilt of potatoes, that a plant infected with Fusarium wilt will produce tubers showing a brownish discoloration of the vascular system, and that a tuber showing vascular browning was produced by an infected plant; further, that a tuber showing such vascular discoloration will, if planted, produce infected plants.

Control measures based upon this hypothesis have been recommended extensively in advising remedial measures to the grower for the control of Fusarium wilt. This method of control appears very simple, i. e., the elimination of infected tubers by discarding entire tubers or cutting away the discolored portions of infected tubers. In recent years a number of papers have been published that do not agree with the earlier reports. Never-

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theless, the popular bulletins on potato diseases still contain this information. Inasmuch as there is this conflict of data and also no published review of the literature, it was thought worth while to present a brief review of the various papers presenting experimental evidence on this point.

Smith and Swingle (1904) were probably the first to draw this conclusion and to recommend such control measures. They state (p. 59):

> The first symptoms in the tuber are nearly always at the stem end in the form of browned or blackened vascular bundles.

They also report that cultures made from the discolored vascular bundles very seldom failed to develop the fungus. As regards control measures, they recommend (p. 60):

> The greatest care should be taken to avoid the infection of healthy land by the planting of diseased tubers. All tubers designed for seed should be cut at the stem end and carefully inspected before planting.

They do not, however, give any detailed experiments in which tubers showing vascular browning and from which the causal organism had been isolated were planted and resulted in wilted plants.

Manns (1911) reports field experiments in which seed having vascular discoloration was planted after various treatments, and compared with healthy seed of the same variety. It is unfortunate that the results are chiefly based upon yield in bushels rather than upon the percentage of diseased plants. He concludes from his experiments that the percentage of increase in yield obtained from cutting away the infected portion of the seed combined with formaldehyde treatment varied with the amount of infection in the seed from —5 per cent to +42 per cent. His results (Table 5, p. 327) show considerable variation. One of the plots shows a decrease in yield when the infected portion of the seed-piece is cut away; others show variable increases in yields. It is noticeable that in the plot showing the greatest increase, 42.26 per cent, the total yield is only about 50 bushels per acre, indicating that there were probably other factors present not under control that were materially reducing the yield. In many instances the variation in yield between plots with the same treatment was as great as the increased yields claimed for the treatnent, showing a considerable experimental error. It is unfortunate that while the different experiments were conducted in 5 different counties, no records of environmental conditions are given, it is very possible that the environmental conditions would influence the amount of the disease and the average yields as much as the amount of infection supposedly present in the seed

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used. It must be remembered that in all these tests we have to do with tubers showing internal discoloration and not necessarily with *Fusarium oxysporum*, as no isolations were reported from the seed tubers. He also notes (p. 325) in one experiment that:

> Fusarium symptoms showed up distinctly on 71.1 per cent of the vines, six weeks before maturity, while the non-infected plot showed only 4.7 per cent of the vines infected.

And again, (p. 328) he reports 76 per cent of tubers showing internal infection when grown from infected seed against less than 1 per cent in tubers from seed in which the infection had been cut away. As a result of his work, Manns concludes (p. 336):

> Internally infected tubers are the chief means of distributing the disease * * * * The infection may be removed from slightly infected seed by clipping away the stem end and following by external treatment with formaldehyde.

Link (1916, p. 188), referring to this method of infection, states:

> Infection carried over by the mother tuber, which is frequent, rarely permits the growth of stems more than 20 cm. high, and seldom allows the development of tubers.

He does not present any experimental data to substantiate this point. If this statement is correct, we should expect that in such experiments as those described by Manns there would be a more marked difference in yield; in fact, we could hardly expect any yield at all.

As far as the author is aware, Bisby (1919) was the first to submit experimental evidence showing that seed having vascular discoloration and having been obtained from wilted vines often produced normal plants. His data (p. 14) indicate that—

> serious disease does not necessarily follow from planting seed from wilted vines, and that no more wilt may result from the use of stem ends than from the use of eye ends.

He mentions, however, the general undesirability of seed from wilted plants and further states (p. 14):

> Selecting seed or clipping the stem ends is, however, not alone sufficient to avoid loss from wilt.

His experiments while not as extensive as those of Manns (1911) were accompanied by some isolations from the seed to determine the presence of *Fusarium oxysporum* and his results are clear-cut.

Haskell (1919), working in New York, states:

> Fusarium oxysporum is undoubtedly disseminated by means of the seed tuber.

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However, he immediately qualifies this statement in the following sentence by saying:

When affected potatoes are planted the plants arising therefrom may be diseased provided the proper conditions exist.

He reports experimental plantings of seed showing distinct stem end browning compared with healthy seed with no vascular discoloration. He bases his results on comparative yields and per cent of diseased seed in the resulting crop, and not on percentage of wilted vines. His results show that the infected seed yielded only 9.6 oz. per hill against 13.9 oz. for healthy seed. No data are given as to the size of the experimental plots or total yield. He also found that in the resulting crop 37 per cent of the tubers from infected seed were diseased against 42 per cent from the healthy seed. He attributes this large amount of infection in the check plot to the fact that infection occurred from the soil. He also reports some experiments with a small number of tubers from which in no case were there 50 per cent of the resulting plants showing disease. He does not mention any control plantings but nevertheless concludes (p. 240) from these experiments that:

They show that the causal factor may be communicated to some extent at least through the seed tubers. On the other hand diseased seed often gives rise to plants that produce a healthy crop. This may be either because those tubers do not harbor the pathogene or because it is present but conditions are unfavorable for sufficient development.

He agrees with Manns (1911) and Bisby (1919), however, in concluding that affected seed results in a lowering of the yield. He advises against the planting of seed containing over 5 per cent of "Fusarium necrosis." Seed having less than this amount can be used providing badly diseased tubers are removed either by "greening" and selection for strong germinating power or by cutting the stem ends and discarding diseased tubers.

MacMillan (1919), studying the disease under irrigated conditions in Colorado, states in his summary (p. 301):

Vascular infection of the seed is not the starting point of disease, but is one of the conditions assisting in bringing about decreased resistance to new infection from the soil.

His experiments are more extensive, especially as to the inspection of individual seed-pieces and cultural studies, than any of the above reviewed work. The results are more clear-cut and are given in percentages of diseased plants rather than in yield. He conducted several experiments where seed having vascular infection and from which Fusarium sp. had been isolated,

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yielded results which would support his conclusions stated above. He divided his tubers in half, and the records of the twins are given from notes taken 4 times during the summer and summarized under 6 different headings, indicating the absence or presence and severity of the disease. There are comparatively few cases in which 2 hills from the same seed-pieces produced similar symptoms of disease, and this percentage was no greater than that found in hills from healthy seed.

He reports experiments where seed tubers of the Early Ohio variety obtained from wilted plants showing vascular discoloration and yielding Fusarium sp. in culture showed less disease than the plots planted with supposedly healthy seed. He found that seed of the Pearl variety obtained from wilted hills produced a larger percentage of hills with no germination or seed-piece rotting, and the author accounts for this by stating (p. 294):

> **Plainly these plants have been weakened by disease, their power of resistance lessened, and their vigor impaired. Examination showed that soil infection acted here to produce the disease.**

It is true that while cultures were made in many cases from diseased seed, the organisms recovered were simply classed as Fusarium sp., which does not prove that *Fusarium oxysporum* was the only organism being dealt with. In general, however, it can be said that these results distinctly disagree with many previous publications and show clearly that, under the conditions of the experiment at least, Fusarium wilt carried over in the seed-piece is not an important factor in transmitting the disease. It is also shown that seed obtained from wilted hills will produce weaker plants that are more susceptible to soil infection.

Edson (1920), studying the relation of vascular discoloration of the seed to the disease, presents the most extensive experiments recorded to date on the relation of vascular discoloration to the presence of a causal organism and to the resulting disease in the plants. He used tubers obtained from 19 different sources and divides these into 3 groups, obscure disease group, healthy group, and parasitic disease group. Cultures were made from seed tubers to determine the presence or absence of organisms, and these tubers were planted in 2 lots, 1 in Wisconsin and the other in Colorado. Results are presented in number and percentage of diseased plants. He finds that vascular discoloration is often present in the absence of any organism, and that organisms are frequently present when the tissue appears healthy; out of 3,203 cultures, only 1,851 revealed the presence of organisms and of these Fusarium sp. were present only 720 times. His field experiments indicate (p. 294)—

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that neither vascular discoloration nor fungus invasion of the tissues of the mother tuber is a guarantee of disease in the resulting plants, nor is their absence a guarantee of health.

He believes the soil to be the chief source of infection. Detailed results are given in a comparison of the plantings at Wisconsin and Colorado. In general there was more disease present in the Colorado plots than in those at Wisconsin, particularly when cut seed was used. He also notes that the plants were often capable of recovery from disease, particularly in Colorado. While these experiments afforded an excellent opportunity for studying the effects of environmental conditions on the progress of the disease, no detailed information as to the environmental conditions under which the experiments were conducted is given except where it is stated (p. 279) that—

one lot being planted on a light, sandy soil, under rainfall, at Waupaca, Wis., and the other on a heavy clay loam under irrigation at Greeley, Colo.

There is no detailed discussion given on the results of these different environmental conditions other than that stated above. While the results show clearly that the soil rather than the seed-piece is the chief source of infection, it also appears from a study of the data that diseased seed results in a larger percentage of infected plants from soil infection. This is shown clearly by a comparison of the three different groups. The "healthy group" compared with the "parasitic disease group" shows a small percentage of diseased plants for both cut and whole seed and under both Wisconsin and Colorado conditions, regardless of the fact that the healthy seed showed nearly as much vascular discoloration (about 42 per cent) as compared with 44 per cent for the parasitic group. As regards the percentage of cultures showing growth, there was 76 per cent for the healthy and only 72 per cent for the parasitic group, and about 25 per cent of the organisms isolated in both cases were either *Fusarium oxysporum* or Fusarium sp. exclusive of *F. discolor var. sulphurem* (Schlect.) App. and Wollenw. Thus, the amount of infection that could have been carried over would have been about the same in both groups, yet the parasitic group yielded about 10 per cent more diseased plants than the healthy group, this being especially true in the case of whole seed. It is worthy of note that in the parasitic group, more diseased plants resulted from whole seed than from cut seed, while the reverse is ture for the healthy group for both Wisconsin and Colorado plots.

As regards the "obscure disease group," he states that a large amount of hereditary disease was present in this group,

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and this is clearly shown from the tables presented. The group shows the smallest number of tubers having vascular discoloration, the lowest percentage of cultures giving growth, and a very low percentage, about 6 per cent, of these positive cultures yielding *Fusarium oxysporum* or Fusarium sp.; and yet the largest percentage of diseased plants is found in this group, being about double that of the parasitic group. Here, again, more disease is found in plants from whole seed than from cut seed. Edson concludes (p. 294) that:

> **Stem-end seed-pieces yielded slightly higher percentages of disease than eye-end pieces, evidently because the stem end is endowed with less physiological resistance.**

McKay (1921), studying some wilt diseases of potatoes in Oregon, also takes up the question of the occurrence of *Fusarium oxysporum* in discolored tubers and the amount of disease resulting therefrom and draws conclusions similar to those of Edson (1920) and MacMillan (1919). The results of his isolations from tubers showing vascular discoloration show clearly that this factor cannot be relied on as a criterion in judging the presence of *F. oxysporum*. He isolated *F. oxysporum* from 295 tubers, or 2.4 percent of all the tubers cultured. His results also indicated that *F. oxysporum* is associated with a darker discoloration of the vascular tissues than either *F. radicicola* Wollenw., or *Verticillium albo-atrum* Reinke and Berthold. His field experiments also show that *F. oxysporum* is transmitted to only a slight extent thru seed tubers. His results are given, not in yields or percentage of diseased plants, but in percentage of resulting tubers yielding the organism. He obtained from seed known to be infected with *F. oxysporum* only 3.8 per cent of *F. oxysporum* infected tubers, while he obtained 1.6 per cent from seed yielding no organisms and 3.5 per cent from seed yielding *F. radicicola*, an organism that is not known to produce a wilt. He also found that stem-end seed-pieces of infected tubers do not seem to give any more disease than the eye ends of the same tubers. He concludes that the difference in eye end and stem end is so slight that it is not advisable to rely on the practice of discarding the stem ends to avoid wilt. Altho no data are given on the number of wilted plants, his results taken from cultures obtained from the tubers

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view that vascular discoloration in the tuber is not always a good index of the presence of *Fusarium oxysporum*, or of the fact that disease will result even tho the organism is present. Nevertheless, such discolored seed appears more susceptible to infection from outside sources. The experimental evidence is rather conflicting in regard to the value of discarding discolored stem ends of seed tubers, no clear-cut evidence having been presented to show that a decrease in Fusarium wilt can be expected by this method of control.

VASCULAR DISCOLORATION OF STEMS

Very few experimental data have been published on the relation between the vascular discoloration of the stem and the presence of *Fusarium oxysporum*. There are, however, a considerable number of published statements, with little or no experimental data, to the effect that the presence of the vascular discoloration of the stem at the surface of the ground and below is one of the chief signs of Fusarium wilt.

Smith and Swingle (1904 p. 14) state:

> Sections cut at the surface of the ground showed only very few hyphae or none at all. There was, however, a marked browning of the tissues, particularly of the vascular ring.

Manns (1911) in describing the symptoms of Fusarium wilt (p. 306) states:

> Cross sections of the large roots and the stem at a level with the ground or below show some or all of the vessels to be of a brown or dull gray discoloration.

He further states (p. 315):

> No difficulty is experienced in taking the parasitic organisms from the infected tubers and plants.

Bisby (1919) discussing the symptoms of potato wilt in Minnesota (p. 8) says:

> A cross section of the lower stem reveals the browning of the vascular system and often of the other tissues as well. This browning may extend to the tips of the plants, though the bundles are often free from hyphae in these upper discolored areas.

He further says that cultures from wilted plants, particularly from the interior of the stem near the surface of the soil, most frequently yielded *Fusarium oxysporum*. However, he readily obtained cultures of *F. oxysporum* from normal plants killed by frost and showing a browning on the inside of the stems at the surface of the ground. In this case it would appear, as Bisby states, that the browning was due to unfavorable environmental

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conditions and that the organism was present more or less saprophytically.

In general it may be said that the use of this sign in diagnosing Fusarium wilt has been based chiefly upon observational evidence, i. e., the presence of a vascular discoloration of the stem accompanying wilt of the plant. It is also based upon the fact that infection obtained by wounding the stem and inserting the inoculum sometimes results in a discoloration of the vascular system by the penetration of the organism. However, as stated by Bisby, browning of the vascular region of the stem may be brought about by frost injury, and the writer will also attempt to prove that browning may also be brought about by other unfavorable environmental conditions.

It is also known that *Fusarium oxysporum* is not the only organism capable of producing this effect. Edson and Shapovalov (1920) found that *F. trichothecioides* Wollenw. was capable of invading the vascular bundles. Link (1916) also obtained in inoculation experiments with *F. trichothecioides* a blackening of the vascular bundles extending even into the petiole and leaf veins. The writer has obtained slight vascular discoloration with such organisms as *Penicillium* sp. and *Rhizopus* sp., and the browning of vascular elements by *Verticillium albo-atrum* is a well-known sign accompanying the wilt caused by that organism. While these organisms may produce symptoms typically different from those of *F. oxysporum*, yet it must be remembered that under field conditions with different environmental factors present we are often concerned with what might be termed atypical cases. Until the differences in symptoms caused by environmental factors are determined, it is not advisable to use such a variable symptom in diagnosing the disease.

It is also true that plants may wilt and die from infection with *Fusarium oxysporum* from the soil, due to a rotting of the roots, without any vascular discoloration of the stem being present. The writer has found this to be true in inoculation experiments as well as under field conditions.

The writer is not aware of any single instance in published

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tions this sign of the disease would not be of value in determining the amount of infection in the field unless accompanied by other symptoms.

Greenhouse Experiments with Seed Having Vascular Discoloration

EXPERIMENT 1, 1915

Tubers of the Rural New Yorker variety were obtained from a field showing a high percentage of wilt on the college farm at East Lansing, Michigan. The tubers showed a distinct brown discoloration for one-fourth to one-half the length of the tuber, and *Fusarium oxysporum* was isolated from a high percentage of these tubers.

Methods.—Tubers were planted February 9 and dug and examined May 8. All tubers were treated with either mercuric chloride or formaldehyde and planted in sterilized soil. The temperature of the greenhouse was abnormally high for the growth of potatoes, about 85°F. (29.5°C.), and as a result the yellowing and wilting of the vines could not be taken as a positive indication of infection. Diagnosis was made by an examination of the vascular system of the stem and tuber, followed by cultural work.

Results.—SET 1.—Thirteen plants were grown from seed tubers showing vascular discoloration. The results showed 4 healthy plants, 5 with a slight browning of the vascular system, and 4 with a heavy infection of the vascular system from which *Fusarium oxysporum* was isolated.

SET 2.—Nine plants were grown from seed tubers with the discolored portion cut away. The results showed 6 healthy plants, 1 with a slight infection, and 2 with a heavy infection of the vascular system.

SET 3.—Eight infected tubers were cut in half, the bud ends and stem ends being planted separately. The bud-end pieces produced 7 healthy plants and 1 slightly infected. The stem-end pieces produced 2 healthy plants and 6 infected.

SET 4.—Seven tubers were planted showing a slight infection. Four of these produced infected plants from which the causal organism was recovered, while 3 plants remained healthy.

SET 5.—Sixteen tubers were planted showing a slight infection; i. e., discoloration did not extend 1 inch. The stem ends were cut away to the depth of 1 inch and discarded; the seed was then treated with formaldehyde, 10 of the resulting plants showed infection.

Further tests were made in the greenhouse in 1920. Tubers showing vascular discoloration were divided into 2 lots and grown at 17° and 27° C. All plants remained healthy.

These few tests proved that the disease was capable under the conditions of the experiment of living over winter in the tuber and producing an infected plant the following year. However, the typical symptoms of wilt were produced in only a few cases, altho the organism was present in the vascular system of the stems. The bud end of infected tubers usually produced healthy plants, altho an attempt to cut away the stem end even of

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slightly infected tubers for a fixed distance of 1 inch did not result in uniformly healthy plants.

One plant of this series showed a condition that the author has frequently found in later experiments and in field trials. The seed tuber showed discoloration of the vascular system and *Fusarium oxysporum* was isolated. The plant produced from this tuber appeared healthy. Upon examination at the close of the experiment the seed-piece was found to be sound, and the causal organism was again isolated from the vascular system. The vascular infection, however, had not progressed far enough to penetrate the tissue of the buds, and the resulting plant remained healthy.

Field Experiments on Seed Transmission

EXPERIMENT 1, 1915

This experiment was conducted on land not previously planted to potatoes for at least 17 years.

Methods.—The infected tubers were all obtained in Michigan and were of the Rural New Yorker variety. They were divided into two groups. 1. Slightly infected seed, i. e., seed in which the vascular discoloration extended not more than ½ inch. 2. Deeply infected seed, i. e., seed with more extensive vascular discoloration. Most of the seed was treated with either mercuric chloride or formaldehyde, either before or after cutting. In other experiments no treatment was given.[1] Notes were taken on the amount of wilt appearing in all rows throughout the experiment, and at digging time each hill was examined for vascular discoloration of the underground stem and also of the tubers produced. In all the following tables the percentages of infected plants are based upon the number of hills germinated, rather than upon the number of hills planted. Healthy tubers of the same variety were used for controls.

Plot 1

Four rows of 65 hills each were planted with healthy seed. Four more rows were planted one-half their length with healthy seed and the other half with slightly infected seed. The seed was cut into stem and bud-end halves, the halves being planted in alternate rows.

Results.—The results of this test are shown in Table 1. The rows planted with infected seed showed considerable wilting and premature dying during August, whereas the healthy rows remained green until frost.

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TABLE 1.—*Percentage of infected plants from healthy seed as compared with plants from seed showing vascular discoloration*

Field Experiment 1. Plot 1

Seed	Plants wilted or with vascular discoloration of stem	Number of blank hills	Resulting number of tubers with vascular discoloration
	Per cent	*Per cent*	*Per cent*
Controls, 4 rows	4.0	25.4	1.3
Infected seed four ½ rows { Bud ends	33.8	16.0	12.4
Infected seed four ½ rows { Stem ends	45.0	50.0	19.3
Controls, four ½ rows	1.6	41.0	.6

No distinct correlation is found between the number of hills germinated and the vascular discoloration of the seed. The small amount of infected plants present in the control rows was probably due to soil infection but does not materially affect the relation between the healthy and diseased seed. The amount of disease present in the progeny from diseased seed was much higher than from the healthy seed. The amount of disease produced by stem-end pieces was only slightly higher than from bud-end halves. The presence of the very small amount of disease in the control halves of the infected rows does not show any indication of the disease being spread thru the crop by cultivation, as suggested by several authors.

In regard to the vascular discoloration of tubers produced, there were more infected tubers found in the rows planted with infected seed than in the controls. The presence of the causal

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healthy. The results presented in Table 2 again show the much greater number of diseased plants in the rows from seed with vascular discoloration. While the amount of infection was slightly higher in the controls than was found in Plot 1, it is

TABLE 2.—*Comparison of healthy seed with seed having deep vascular discoloration*

Field Experiment 1, Plot 2

Row	Seed	Plants wilted or with vascular discoloration of stem	Number of hills blank	Resulting number of tubers with vascular discoloration
		Per cent	*Per cent*	*Per cent*
1	Healthy	4.8	6.0	1.6
2	Diseased	68.0	18.1	40.0
3	Healthy	4.8	4.6	2.2
4	Diseased	64.0	24.3	28.0
5	Healthy	8.8	13.6	19.0
6	Healthy	10.0	33.0	2.8
7	Diseased	75.0	21.1	50.5
8	Healthy	9.4	3.3	2.8
9	Healthy	8.5	12.1	2.4
10	Healthy	3.9	13.6	.8
	Average of healthy and diseased rows			
Rows 7	Healthy	7.1	12.3	4.2
3	Diseased	69.0	21.1	39.5

not probable that it was spread from adjacent infected rows, inasmuch as Rows 1 and 3 show less infection than other control rows farther removed from the diseased seed. There was no correlation between diseased seed and the number of hills failing to germinate. Altho the averages show greater failure to germi-

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nate in the rows planted with diseased seed, this does not hold true when the individual rows are examined. As in Plot 1, there was a greater number of diseased tubers produced from diseased rows than from healthy rows.

Plot 3

This plot was composed of 8 rows of 65 plants each. All seed used in this test was discolored for a considerable depth. The infected portion of some of the seed was cut away to determine the effect upon the transmission of the disease. The bud and stem ends of tubers were kept separate in every case and planted in alternate rows.

Results.—The results presented in Table 3 show that in the case of a deep infection it was not possible to remove successfully all the infected portion of the tuber. There was also no clear relation between the amount of infection present in plants produced from bud ends and stem ends. Neither was there any relation between cutting away the infected portion and the num-

TABLE 3.—*Comparison of plants grown from bud-ends and stem-ends of tubers showing vascular discoloration and also of tubers with this discoloration cut away*

Field Experiment 1, Plot 3

Row	Seed	Plants wilted or with vascular discoloration of stem	Number of blank hills	Number of tubers with vascular discoloration
		Per cent	*Per cent*	*Per cent*
1	No treatment, bud end...	85.0	21.6	37.7
2	No treatment, stem end..	50.0	73.5	22.2
3	No treatment, bud end...	75.0	41.0	45.0
4	No treatment, bud end...	93.0	26.0	47.0
5	No treatment, stem end..	87.0	42.0	35.0
6	Inf. cut away, bud end...	75.0	22.0	32.0
7	Inf. cut away, stem end..	62.0	33.0	19.0
8	Inf. cut away, bud end...	79.0	53.0	36.0

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ber of blank hills; there was a slightly greater average percentage (44.4 per cent) of blank hills in the "no treatment" seed than in the seed from which infection was cut away (36 per cent). Also, there was a difference in the number of blank hills planted with stem ends, 56.1 average per cent, as compared with 28.7 average per cent for plants from bud ends. In regard to the resulting tubers showing vascular discoloration, there was no relation either between bud and stem ends or between cut and uncut seed.

Plot 4

In this plot tubers with slight infection were divided into 2 sets, one-half of the tubers having the infected portion cut away. Two rows of 65 plants each were planted in each set.

TABLE 4.—*Effect of cutting away discolored portions of tubers having only a slight discoloration*

Field Experiment 1, Plot 4

Treatment	Plants wilted or with vascular discoloration of stem	Number of blank hills	Number of tubers with vascular discoloration
	Per cent	*Per cent*	*Per cent*
Infection not cut away..	42.0	37.5	17.5
Infection cut away.....	28.2	35.0	13.5

Results.—There was less infection from seed showing slight discoloration than was found in Plot 3 with plants from seed with a deep discoloration. It was also noticeable that there were nearly 15 per cent fewer infected plants when the infected portion of the seed was removed. However, the amount of infection was still so high that this was apparently not a very practical method of controlling the disease. There was no apparent difference in the amount of germination. There were slightly fewer resulting tubers showing discoloration when the infected portion of the seed was removed.

EXPERIMENT 2, 1916

Further experiments on the transmission of Fusarium wilt by means of internally infected seed, as well as attempted control measures, were undertaken. The method of work was very similar to that described in the previous experiments except that it was carried out on a larger scale.

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The results were so uniformly negative that no detailed data will be presented. Very few of the plants in any of the plots showed even slight symptoms of wilt during the summer. At digging time over 90 per cent of the plants, including not only the infected seed both cut and uncut, and with various treatments, but also all controls, showed a browning of the vascular system of both the stems and tubers. Attempts to isolate the causal organism resulted in failures except in a very few instances out of hundreds of isolations. It is interesting to note that most of the infected seed used in this experiment came from a field showing almost 100 per cent wilt the previous season. The conditions of both soil and air thruout the experiment were radically different from those present the preceding year (Field Experiment 1), when such marked wilting occurred. The detailed meteorological data for this experiment are given on page 17. The weather thruout all of July and part of August was extremely hot and dry in contrast with the moist cool summer of 1915. These conditions, which were found to be unfavorable for infection in the inoculation experiments (p. 17), are also unfavorable for the development of the disease from infected seed.

The type of brown discoloration present in this experiment was not due to infection with Fusarium wilt, but rather to the unfavorable environmental conditions under which the crop was growing. This non-parasitic browning was also found in inoculation experiments (p. 17) and is also mentioned by Edson (1920) as having been observed in plots in the vicinity of Washington.

EXPERIMENT 3

In the spring of 1921 a small lot of Early Ohio tubers showing varying degrees of vascular discoloration were divided up into three lots; slight, medium, and deep discoloration. Each tuber was cut in half and the corresponding halves planted at Lincoln and at Mitchell, Nebraska. Each tuber was divided into stem-end and bud-end halves. The lot at Mitchell was grown under dry conditions. The weather for both locations is shown in Figures 3, 4, and 5.

The fields were examined several times during the growing season and at no time was there any typical wilt present in any of the lots. The results at digging time showed a considerable number of plants with vascular discoloration in the stems and tubers. The number of plants was too small to draw general conclusions, altho there appeared no clear-cut difference in the number of stems showing vascular discoloration under the 2 different

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environmental conditions, or in the various lots of seed. Plants from seed with slight discoloration grown at Lincoln had a smaller number of vascular discolored stems and yet these same plants show the greatest number of tubers having vascular discoloration. It was noticeable that the yield was much greater at Mitchell, showing a more favorable environment for the plants.

In Table 5 is seen a comparison of the yield of deeply infected seed with the other 2 lots. While no wilting occurred and the percentage of plants showing vascular discolored stems and tubers was no greater with deeply infected seed than in the other

TABLE 5.—*Average yield in grams per plant from slight, medium, and deeply discolored seed tubers*

Field Experiment 3

Seed	Yield per plant in grams.	
	Lincoln	Mitchell
Slight discoloration	143	430
Medium discoloration	154	297
Deep discoloration	71	192

lots, it is clearly seen that the yield per plant was materially lessened both at Mitchell and Lincoln. This shows further evidence that such seed should not be used even tho under certain conditions the disease is not transmitted. The largest yield of healthy tubers was found in the lot planted with slightly infected seed. The yield from bud ends was also considerably greater than the yield from stem ends.

CONCLUSIONS

The review of the literature shows that in the earlier papers on Fusarium wilt it was generally accepted that a plant showing Fusarium wilt would produce tubers with vascular discoloration, indicating the presence of the causal organism, and that these tubers would in turn produce an infected plant. Recommended control methods were based upon this hypothesis. The later papers show a decided shift in this attitude and clearly state that this hypothesis does not hold and that the seed tuber is not the chief source of infection; further that the cutting away of sup-

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posedly infected portions of the tuber may be really harmful rather than beneficial.

The experimental evidence presented in this paper shows that in the greenhouse, in tests where sterilized soil was used, the disease was carried over in the tuber. The percentage of infection from such tubers was small, but still as high as in the previous experiments where artificial inoculations with pure cultures were employed. Very often infected tubers showing vascular discoloration, and also yielding the causal organism in pure culture, failed to produce wilted plants. In many instances, altho no wilting was produced, the causal organism was found to be present in the stem and roots of the plants. Experiments conducted in the field showed that under the conditions of Field Experiment 1 (p. 29) Fusarium wilt was transmitted thru the seed tubers and that the amount of resulting disease was directly proportional to the severity of the infection in the seed, as indicated by the depth of discoloration of the vascular system. It was also found that in cases of slight discoloration attempts to remove the infected portion of the tuber resulted in a decrease of about 14 per cent in the amount of disease. With deeply infected tubers, such attempted removal of infected portions of the seed resulted in no decrease in the amount of disease, and in these deeply infected tubers there was no appreciable difference in the amount of disease in the progeny of stem and bud-end seed-pieces.

It was also shown the following year (Field Experiment 2, p. 33) that under certain other environmental conditions the disease was not transmitted thru the tubers and that vascular discoloration of the stem does not always give a good indication of the amount of disease present, altho, as indicated in Experiment 3 (p. 34), the depth of the vascular discoloration can often be correlated with a decrease in yield, thus indicating a lowering of the vitality of the seed.

Vascular discoloration of both stem and tuber was often found in the absence of any causal organism. This was particularly marked in Experiment 2, (p. 33) and Inoculation Experiment 1, (p. 17) this appearing to be due directly to the hot, dry weather. The same type of discoloration was observed in 1921 on potatoes grown in western Nebraska under dry land conditions. Hot weather prevailed thruout the summer and there was very little moisture present until late in the season. The crop, however, appeared very thrifty and healthy in the fields and the potatoes were certified for seed. The sale of these potatoes outside of the State resulted in many complaints, claiming that

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the seed was poor in general vigor and was infected with Fusarium wilt. This was due partly to the high amount of vascular discoloration in the seed, altho there was no wilt present in the field. The tubers were rather badly malformed owing to renewed growth late in the season. Nevertheless, this stock when planted at various points in the South showed the smallest amount of disease and the greatest yields of any of the Nebraska potatoes tested in the same trials.

Thus, it is evident that vascular discoloration is not a good indication of Fusarium wilt, altho under certain environmental conditions we do get a considerable amount of wilt by planting such seed, while under other conditions no wilting results. It is to be remembered that in the plots where the disease resulted from planting seed having vascular discoloration the tubers were obtained from stock known to be infected the previous year as indicated by the large amount of wilt, and not simply tubers showing vascular discoloration. In other words, vascular discoloration is not a good criterion of the presence of Fusarium unless it be produced by a wilted plant, and even then the chances are that it will not reproduce the disease the following year by means of seed infection.

INFECTION FROM THE SOIL THRU THE ROOTS OR STEM

It is a well-known fact that *Fusarium oxysporum* can live as a soil saprophyte for many years. It has also been claimed by various workers that *F. oxysporum* causes a wilt of the potato plant by the entrance of the organism thru the root hairs from the soil. While this method of infection has been generally accepted as one of the modes of entrance of the organism, very little positive experimental work has been published to prove this point. The following work was undertaken in an attempt to either prove or disprove this theory, and if true, to determine the conditions favoring such a method of infection.

The author has observed many cases in various parts of the United States, but especially in Michigan and Nebraska, where healthy seed planted on land not previously cropped has resulted in a considerable number of wilted plants. These plants appeared to have become infected thru the roots; very often there was only a discoloration of the vascular system without any root rotting and without a rot of the seed-piece. It was this type of infection that prevailed in Michigan in 1914 and 1915 and lead to the undertaking of the present investigation.

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Review of Literature

Smith and Swingle (1904) in their early description of the disease state (p. 13):

The disease ordinarily enters the plant through the roots and slowly spreads until the whole root system, a few centimeters of the lower part of the stem, the underground stems bearing the tubers, and the tubers themselves are invaded by the fungus.

They present no detailed experimental evidence to support their observations.

Manns (1911) also claims that the disease makes its attack thru the root system. This results in the root hairs and smaller secondary roots of affected plants being entirely destroyed and thus causing the premature death of the plant. He found by planting healthy seed on heavily infested soil as compared with slightly infested soil that there was more wilt and a reduction in yield from 125.6 bushels to 90 bushels per acre. He tested the infection powers of "sick" soil by adding a little of this soil to hills of potatoes growing in sterilized soil. He says (p. 317):

The disease came on much more definitely under the sick soil infection than it did where pure artificial cultures were used without incisions or root injury. The great difference between sick soil infection, and that from pure cultures or even internal seed infection, is that in the use of sick soil the roots are attacked at practically every point, while with pure cultures, or seed internally infected, the fungus attacks only in close proximity to the main root, while most of the secondary roots and the root hairs remain healthy.

He does not, however, give any detailed data in regard to infection from the soil by use of pure cultures.

Link (1916) does not report uniformly successful results with soil inoculations of *Fusarium oxysporum*. He reports one experiment of 5 plants in which the soil was inoculated with rice cultures of *F. oxysporum*. No plants came up in the inoculated soil, whereas the controls appeared healthy. He states that this experiment was repeated several times, but in no case were the results so striking. In fact, in one experiment no infection re-

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gain in resistance in the plants, due to a change in the soil, tubers, or the organism.

Pratt (1916) studied the amount of disease present when healthy seed was planted on virgin desert soil in Idaho. He found wilt to be present in every plot, and isolated the organism from stems showing vascular discoloration. He also states that 80 per cent of the tubers showing vascular discoloration yielded cultures of either *Fusarium oxysporum* or *F. radicicola.* Basing his percentages on this basis, he found on tubers grown on land previously planted to alfalfa and grain 26 per cent vascular infection, while on the virgin desert land plots he found 29.3 per cent.

Bisby (1919), in discussing the results of attempted infection of potato plants by artificially infected soil or seed-piece, says they were often unsuccessful and concludes (p. 12):

It is evident that *F. oxysporum* is not vigorously parasitic to actively growing potato plants.

He thought that these results may have been due to too low a temperature and made further tests with heavily inoculated soil at soil temperatures of 20° to 30° C. with a high humidity, and produced a stem rot or "foot rot" of the plants. He further states that the higher temperatures in the warm chambers were unfavorable to the potato and the plants died sooner than corresponding plants left outside.

MacMillan (1919) states that in only 6 plants out of many hundreds examined in 1916 and 1917 was root infection determined as the probable cause of Fusarium wilt in the Greeley section of Colorado. He notes that in 1918, when the soil temperature was 6°F. above the average for the month of June of the two preceding years, plants of the Charles Downing variety were badly diseased by being attacked thru the fine roots and root hairs and concludes (p. 284):

Higher temperatures seem to be necessary for root infection.

Haskell (1919) finds that Fusarium wilt in Dutchess County, New York, is primarily a root and stem rot. He was the first worker to report detailed experimental work under controlled temperatures. In 1915 he inoculated sterilized soil with pure cultures of *Fusarium oxysporum*, one plot before planting, another when the plants were 6 inches high, and the third plot left as a check; the number of plants is not stated. The results were not uniform and this he attributed to the fact that the greenhouse temperatures were too low for infection, 18°-21° in the day and

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13°-15.5°C. at night. He repeated this, using the same soil and growing the plants in the summer when the temperatures were higher, and found that many of the new tubers showed marked stem-end browning, from which the fungus was isolated. Another experiment was conducted with 6 plants, 4 inoculated with a flask culture of *F. oxysporum* No. 3395 (the same as Strain No. 8, used by the writer in many experiments). The plants were kept in a water bath at 36° (air temperature not given). He found that the root systems became diseased and that some of the stems showed lesions, and the organism was isolated. He states (p. 237):

> **Although the tops of the diseased plants did not resemble those that are affected with Fusarium wilt as it appears in the field, the affected root system and the lesions on the outside and within the stem were exactly like those that occur in the field.**

He repeated this experiment, keeping the crocks in the water bath at 36°-39°C. Again he was apparently unable to produce typical Fusarium wilted plants, altho he states (p. 237):

> **An examination of the xylem of inoculated plants showed it to be badly discolored in most of the stems. In some instances the checks also showed this condition but not so badly.**

The writer is in doubt as to just how much of this discoloration of the xylem reported by Haskell was due to the extremely high temperatures, as vascular browning can be produced by submitting plants to very high temperatures even for short periods, and this diseased tissue becomes easily infected with Fusaria from the soil. It is clear, however, from Haskell's work that even with high soil temperatures it is difficult to obtain 100 per cent infection or to produce typical field symptoms of wilt. Haskell also tested soil infection by growing healthy seed in the greenhouse in soil brought from a badly diseased field. Twelve plants were grown in this soil and 12 in sterilized soil. No typical symptoms of Fusarium wilt appeared. The roots in both plots appeared diseased altho *Fusarium oxysporum* was isolated only from the plants on unsterilized soil. In regard to soil infection, Haskell further makes the statement (p. 242):

> **Land that has produced a diseased crop one year is practically certain to do so the next if potatoes are planted.**

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able for the disease and unfavorable for the host and that it is during the hot weather that wilt develops. How then account for the writer's results in Michigan in 1916 when practically no wilting appeared on badly infested soil during the hottest summer in years. Haskell concludes (p. 252) that—

temperature is probably the most important factor limiting the development of Fusarium wilt in southeastern New York.

He believes that the amount of rainfall and hence soil moisture has very little to do with the prevalence of the disease. He does think, however, that with a low soil moisture diseased plants will wilt quicker.

This review of the literature shows a general conformity of opinion among the earlier workers on this disease, who claim that infection can take place from the soil thru the roots. There are some conflicting statements as to whether this type of infection is confined to the vascular system of the roots and stems, or whether it results in a rotting of the root system. It is noticeable that the only writer working under western irrigated conditions, MacMillan (1919), claims that only a very small amount of infection occurs thru the roots. It is generally stated that high soil temperatures favor the development of this type of infection. Haskell reports successful soil inoculation experiments at soil temperatures of 36° to 40°C. This temperature is the extreme maximum temperature for the growth of both host and organism. No experimental work is reported regarding the relation of soil moisture to infection.

Field Experiments with Infested Soil, 1914-15-16

During 1914 a field of Rural New Yorker potatoes on the college farm at the Michigan Agricultural College showed over 90 per cent of the plants affected with Fusarium wilt. The plants wilted early in the year. *Fusarium oxysporum* was repeatedly isolated from stems and tubers of wilted plants showing vascular discoloration as well as from the soil.

In 1915 four rows, 330 feet long, of this heavily infested soil were planted with healthy seed. Very few of the plants showed the early symptoms of the disease and very little wilting occurred until just before digging time. The plants in these 4 rows were found to be 47 per cent infected as determined by actual wilting, vascular discoloration, root infection, and cultural examinations; while the same seed planted on soil not previously planted to potatoes showed only 3 per cent infection.

In 1916 four more rows were planted on this land that had

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been in clover the previous year. A few plants were wilted in August and at the end of the experiment only about 20 plants, or 4.5 per cent of the total number of plants, showed wilting symptoms. When dug, the stems and tubers of all plants showed vascular browning similar to that noted on page 34, but no successful isolations were made except from the 20 wilted plants. The weather conditions for this year are given on page 17. An examination of the infected plants showed in every instance that infection took place thru the roots rather than thru the seed-piece. The amount of rotting of the root system was very slight, and no rotting of the underground stems was observed except in the few cases where wilting took place early in the season and the plants were not dug until the end of the experiment. The infection in practically all cases was confined to the small root hairs and the vascular system of the main roots and underground stem.

While this experiment shows at first glance a reduction of the wilt, the first year from 90 per cent to 47 per cent, and after one year's rotation to 3 per cent, it must be remembered that climatic conditions were probably a greater factor than was the rotation used.

Greenhouse Experiments

In the following experiments, only vigorous plants grown from healthy seed were used, the seed tubers being carefully examined for the absence of vascular infection before planting. The soil inoculations were made by mixing thoroly with the soil a suspension of spores and mycelium in sterile water.

EXPERIMENT 1. 1915

Tubers of the Green Mountain variety were planted February 8. The inoculations were made when the plants were about one foot in height on March 1, and the final results were taken May 10. The inoculum was obtained from cultures of *Fusarium oxysporum* No. 1.

Set 1.—Nine plants were grown in inoculated soil. None of these plants showed typical wilt and at the close of the experiment no browning of the vascular system of either the roots or the stems was observed.

Set 2.—Ten plants were grown in inoculated soil. The roots of these plants were slightly injured, but not enough to impair their vigor. Three of these plants showed a very heavy infection, the typical Fusarium wilt appeared rather early, and the fungus was found to be present very

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done in order to observe the possibility of *F. oxysporum* obtaining an entrance into the roots thru the Rhizoctonia lesions. No wilting occurred and no browning of the vascular system was observed. Rhizoctonia lesions were found on 2 of these plants.

Set 4.—Five plants were grown in soil inoculated by placing pieces of potatoes internally infected with *Fusarium oxysporum* in the soil close to the roots. Three of these plants showed a slight wilt and a slight browning of the vascular system. Two plants remained healthy.

Set 5.—Five plants were grown in soil inoculated as in Set 4, but the infected pieces were placed next to injured roots. Two plants showed a heavy infection of the wilt similar to those of Set 2. Three plants remained healthy.

Set 6.—Twelve plants were used as controls. In some a wilting occurred somewhat similar to that of the inoculated plants, so the wilting of the plants could not be taken as a sure sign of the disease. However, no browning of the vascular system was found in any of the controls and careful microscopic and cultural work failed to reveal the presence of the fungus.

EXPERIMENT 2, NOVEMBER, 1915

Potato plants of the Russet Rural variety were used in the greenhouse for inoculation experiments similar to the previous ones. The inoculum was obtained from cultures of *Fusarium oxysporum* No. 1.

Set 1.—The roots of 2 plants were injured and the soil inoculated. One of these plants produced typical wilt and showed vascular browning. The other plant remained healthy.

Set 2.—Two plants were inoculated as in Set 1 but the roots were not inujred. Both of these plants remained healthy.

Set 3.—Four plants used as controls remained healthy.

EXPERIMENT 3, MARCH, 1917

Fourteen tubers of the Rural New Yorker variety were planted in the greenhouse. The soil was inoculated with *Fusarium oxysporum* No. 8 just as the shoots were showing at the surface of the ground. One plant showed slight symptoms of the wilt, and the fine rootlets when observed under the microscope were found to be invaded by the fungus. The other 13 plants remained healthy. Three plants used as controls remained healthy.

EXPERIMENT 4, MARCH, 1917

Four tubers of the Rural New Yorker variety were planted in the soil previously used in Experiment 3. All the plants when very young showed symptoms of the wilt. When these plants were dug up and examined, the roots were found to be heavily invaded and the entire underground portion of the plant showed the presence of the fungus. Isolations were made from each plant and the organism recovered in all cases. Four other plants kept as controls remained healthy.

EXPERIMENT 5, MARCH, 1917

Twelve plants of the same variety as those of the previous experiment were used. The soil was inoculated just as the sprouts were breaking thru the ground. All the plants remained healthy.

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EXPERIMENT 6, 1920

In these tests the soil was sterilized and then inoculated with 3-weeks-old rice cultures of *Fusarium oxysporum* No. 33. The experiment was started February 21; the results were taken May 5. Two temperatures were used.

Set 1.—Five plants were placed in a greenhouse having a mean temperature of about 17° C. All 5 plants remained healthy.

Set 2.—Three plants were grown in a greenhouse with a mean temperature of about 27° C. Plant 1 showed no wilt, 2 stems out of 4 had brown lesions at the base of the stem, and there was slight root injury but no browning of the vascular system. *Fusarium oxysporum* was recovered from the lesions. All the underground stems of plant 2 showed lesions, also some of the roots and stolons. There was no wilt or vascular infection. *F. oxysporum* was recovered from the lesions. Plant 3 showed no wilt or vascular invasion, but 2 of the stems showed numerous lesions and considerable root injury. *F. oxysporum* was recovered from the stems and the roots. In these plants the lesions caused by *F. oxysporum* on the underground stems were entirely superficial, while on the roots the penetration was deeper and the injury much greater, often cutting off the root.

EXPERIMENT 7, 1920

On February 16, 6 pots, 4 with inoculated soil and 2 uninoculated controls were planted with Irish Cobbler seed and kept at 25° C. until March 10 when they were all about 6 inches high with a good even growth and no signs of disease. They were then removed to a greenhouse kept at 30°-33°. On March 20 the plants growing in inoculated soil were badly yellowed and wilted. The controls, altho entirely dead above ground, showed no signs of disease in the underground parts, the stem, roots, and stolons being healthy. *Fusarium oxysporum* was recovered from the rotted portion of the stem of inoculated plants.

A summary of these soil inoculation tests shows that out of 80 plants inoculated in various ways only 14 wilted, 11 were infected but did not wilt, and 55 remained healthy. The results show that the greatest amount of wilt was obtained when the soil was inoculated before planting or when the plant was very young. There was no difference in the amount of infection in the different varieties of potatoes. Injury to the roots resulted in a higher percentage of infection. The results also in-

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"tanks" were made, but the principle employed was essentially the same. In these "tanks" the plants were grown in galvanized iron cans immersed in a well-insulated water bath, 21x39x27½ inches in size, heated electrically and controlled by electric thermostats. The temperature of the soil in all the following "tank" experiments was taken twice daily at the depth of 3 inches. The soil moisture content was kept approximately constant by weighing the pots and adding the necessary water about 3 times a week, and as the plants grew larger, the water was added daily. In some of the experiments the surface of the soil was covered with mineral wool and in the latter experiments with crushed stone to prevent a rapid change in the temperature of the surface soil and also to prevent the drying out of the surface soil. Water was added thru a test tube to an inverted clay pot in the center of the container and was also added to the surface of the soil. With this combination of surface and subsoil watering the moisture was found after numerous tests to be very well distributed throut the soil. It is obvious of course that the soil moisture did not remain constant during the experiment, and varied according to the rapidity of transpirtation and the frequency of watering. The soil was only at the specified moisture content immediately after watering and gradually decreased until the next watering. It is also true that during the experiment the soil would settle, and this packing would result in a decrease in the moisture holding capacity. This is counteracted to some extent by the increase in the weight of the plant, this increase not being taken into account in the weighings. The following percentages show an average of several tests made to determine the changes during the experiment in the moisture content of the soil with growing potato plants. Composite samples were taken from various parts of the container.

	Set 1	Set 2	Set 3
	Per cent	Per cent	Per cent
Moisture content (dry weight) at start.....	13.6	20.4	27.2
Moisture content (dry weight) at end.....	14.0	20.6	23.8

Thus we find the greatest change occurring at the higher moisture contents where the weight of the plant is greater than at the lower soil moistures; the cans at 80 per cent of the moisture holding capacity[1] (27.2 per cent dry weight) being 70 per cent at the close of the experiment. The difference at 40 and 60 per cent of the moisture holding capacity was very slight.

The plants were watered often enough so that it was never necessary to add more than 200 c. c. of water, and usually only about 100 c. c., so that just previous to watering or when the soil was at the lowest moisture content it was usually not more than 10 per cent of the moisture holding

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EXPERIMENT 1, FEBRUARY 16 TO APRIL 8, 1920

Methods.—Healthy Irish Cobbler potatoes were treated with formaldehyde and sprouted for 2 weeks in a cool place. The tubers were cut in half for seed. The soil used was one part leaf mold and 2½ parts soil sterilized for 8 hours at 2½ pounds pressure. About 3,000 grams of soil, dry weight, was used in each can. The soil had a moisture holding capacity of 40.5 per cent dry weight. During the experiment it was kept at 29.0 per cent dry weight, or about 72 per cent of the moisture holding capacity. The soil was inoculated just previous to planting with a spore suspension in water of a 14-day-old rice culture of *Fusarium oxysporum* No. 33. Immediately after planting the cans were removed to the desired temperature.

Five different soil temperatures were used; 9 plants being grown at each temperature, 6 with inoculatd soil, and 3 uninoculated controls. The temperatures used were 12°, 18°, 24°, 30°, and 36° C. Readings were taken twice daily and the average thruout the experiment was 11.8°, 17.5°, 23.8°, 30.1°, and 35.7°. The temperatures did not vary more than 1° on each side of the average. The air temperature was maintained at approximately 17°.

Results.—The potatoes were planted February 16, and by February 23 the sprouts were coming thru at 18°, 24°, and 30°C. The most rapid growth was at 24°. At 12°, the plants were slower in getting started. They were all up on March 3. At 36° all the seed-pieces rotted before the sprouts started. The plants at 18° produced a very even stand of vigorous, healthy plants, and these plants along with those at 12° remained healthy thruout the experiment with no apparent difference between the inoculated plants and the controls. One plant at 30° was wilted down by March 10 and the other plants at this temperature all showed a yellowing of the lower leaves apparently due to the high soil temperature.

The plants were dug on April 8 and the tops, underground stems, and roots examined and cultures made from plants showing disease. The results of this experiment are tabulated in Table 6. It is apparent from this table that no infection took place at 12° and 18°C. At 24° there was no marked difference in the tops of control and inoculated plants; in only one case were the tops wilted. Three plants had slight root injury and *Fusarium oxysporum* was isolated. At 30° 5 of the 6 inoculated plants showed varying but distinct symptoms of wilt and when examined were found to have vascular discoloration of the stem

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TABLE 6.—*Relation of soil temperature to infection of Irish Cobbler potatoes from soil inoculated with Fusarium oxysporum No. 33.*

Experiment 1[1]

Soil temperature	Treatment of plants		Symptoms				Cultures of *F. oxysporum*	
			Wilt	Vascular discoloration	Stem rot	Root injury	From roots	From stems
Degrees C. 12	6 inoculated plants, 3 controls, all healthy							
18	6 inoculated plants, 3 controls, all healthy							
24	Inoculated	1	—	—	—	1	+	—
		2	—	—	—	1	+	—
		3	2	2	3	1	—	+
		4	—	—	—	—	0	0
		5	—	—	—	—	—	—
		6	—	1	—	—	—	—
	Control...	7	—	—	—	—	0	0
		8	—	—	—	—	0	—
		9	—	—	—	—	—	—
30	Inoculated	1	3	3	3	3	+	+
		2	2	2	2	1	+	+
		3	—	—	—	1	+	—
		4	3	3	3	3	+	+
		5	1	—	—	1	+	—
		6	3	3	3	—	—	—
	Control...	7	—	—	—	—	—	—
		8	—	—	—	1	0	0
		9	1	—	1	—	—	—
36	6 inoculated plants, 3 controls, all seed rotted							

The figures in Tables 8 to 12 represent the degree of infection; 1 = slight, 2 = medium, 3 = serious. In the last two columns the results of isolations are shown; 0 = negative culture, + = positive culture, — = no culture made.

[1] The moisture content of the soil was kept as 72 per cent of the moisture holding capacity, or 29 per cent dry weight.

and that above 18° the amount of infection in the inoculated plants increased with the increase in temperature up to 30°C. At 36° the temperature was too high for good germination of the seed. It is noticeable that only 6 plants in the experiment

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showed positive symptoms of wilt or stem injury, whereas 8 plants showed root injury. The controls remained healthy except at 36° and in the case of one stem of a control plant at 30°.

EXPERIMENT 2, APRIL, 1920

The methods used in this experiment were similar to those in the previous experiment except that Rural New Yorker potatoes were used instead of Irish Cobblers. The soil moisture content was also lowered. The moisture holding content of the soil used was 49.7 per cent dry weight. The sets at the various temperatures were divided into two series, one in which the soil was held at 51 per cent of the moisture holding capacity (25.3 per cent dry weight) and the other at 57 per cent (28.3 per cent dry weight). The following temperatures were used.

Set No. 1: Air temperature 17°C. Soil temperature 18°, 22°, 26°, 30°, and 34°C.

Set No. 2: Air temperature 27°C. Soil temperature 18° and 27°C.

The seed-pieces at all the temperatures were completely rotted before the sprouts got above the ground, both in the controls and in the inoculated pots. There were a few weak sprouts appearing above the ground but not enough to continue the experiment.

EXPERIMENT 3, NOVEMBER 5 TO FEBRUARY 4, 1921

This experiment and the following soil temperature experiments were conducted at the Nebraska Agricultural Experiment Station; and while the same general methods as those outlined in Experiment 1 were used, there were slight differences in each experiment. In Experiment 3 an attempt was made to obtain further information in regard to the effect of soil moisture as well as temperature upon the disease; 2 different soil moistures were therefore used at each temperature.

Methods.—Owing to the fact that no infection was obtained in Experiment 1 at the low soil temperature of 12°, this temperature was omitted in the present experiment and the soil held at 4° intervals instead of the 6° C. intervals as in Experiment 1. Six "Wisconsin soil temperature tanks" were used. In each "tank" 8 cans holding about 10 kilos of soil (dry weight) were used. The same amount of soil was

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out the experiment but the extremes did not overlap and usually the temperatures did not vary more than 1°. The air temperature was kept at approximately 18°, altho during the last 2 weeks of the experiment the air temperature ran slightly higher, averaging about 20°. The soil used was disinfected with formaldehyde and allowed to air out before planting. All the soil was inoculated just before planting with 14-day-old rice cultures of *Fusarium oxysporum* No. 33. Early Ohio tubers were then cut and sprouted in damp excelsior and when planted the sprouts were ¼ to ½ inch long. Immediately after planting, the cans were placed at the desired temperature and brought up to the desired soil moisture content, the water being added as in Experiment 1.

Results.—The plants were examined daily thruout the experiment and any symptoms of disease were noted. These along with the results obtained at digging time are presented briefly in Table 7. The only temperature at which positive wilting symptoms appeared was 36°C. At this temperature many of the sprouts appeared to be killed before they reached the surface of the ground. They then sent out secondary sprouts which produced tops never exceeding 10 inches in height. Both control plants remained healthy. At 32° no wilting occurred, altho most of the plants were considerably dwarfed as at 36°. It was noticeable at these 2 high temperatures, and especially at 36°, that the root systems were very small and remained near the surface of the soil. This combined with the high soil temperature made it impossible to keep the upper 2 inches of soil at the same moisture content as the rest of the pots, even when insulated with mineral wool. Thus the actual soil moisture surrounding the roots at 36° was considerably less than indicated in the table.

No vascular discoloration of the stems was found in any of the control plants at any of the temperatures. There were no marked differences in the amounts of vascular discoloration at any of the temperatures between 20° and 36°C. As regards soil moisture, 10 plants at 60 per cent of the moisture holding capacity showed vascular discoloration and only 3 at 40 per cent. The amount of stem rot was found to run parallel with the vascular discoloration and in most cases, the 2 symptoms appeared on the same plant. The amount of root injury appeared to be greatest at temperatures from 24° to 36°, altho there was very slight injury to 2 plants at 16°. At the high temperatures the injury appeared greater and isolations from these roots always yielded *Fusarium oxysporum*. Three control plants showed root injury at 28° and 32°, and *F. oxysporum* was recovered from one of them. The causal organism was also recovered from the stems of 8 inoculated plants showing either vascular discoloration or stem rot, while 2 plants with similar symptoms gave negative results in culture.

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TABLE 7.—*Relation of soil temperature and moisture to infection of Early Ohio potatoes from soil inoculated with Fusarium oxysporum No. 33*

Experiment 3

Soil temperature	Soil moisture[1]	Treatment of plants	Symptoms				Cultures of *F. oxysporum*	
			Wilt	Vascular discoloration	Stem rot	Root injury	From roots	From stems
Degrees C.	*Per cent*							
16	40	Control.....1	—	—	—	—	—	—
		Inoculated 2	—	—	1	1	—	—
		Inoculated 3	—	—	—	—	—	—
		Inoculated 4	—	—	—	1	—	—
	60	Control.....1	—	—	—	—	—	—
		Inoculated 2	—	—	—	—	—	—
		Inoculated 3	—	1	1	—	—	+
		Inoculated 4	—	—	—	—	—	—
20	40	Control.....1	—	—	—	—	—	—
		Inoculated 2	—	—	—	—	—	—
		Inoculated 3	—	1	1	—	—	—
		Inoculated 4	—	—	—	—	—	—
	60	Control.....1	—	—	—	—	—	—
		Inoculated 2	—	—	—	—	—	—
		Inoculated 3	—	1	1	—	—	+
		Inoculated 4	—	1	1	—	—	+
24	40	Control.....1	—	—	—	—	—	—
		Inoculated 2	—	—	—	—	—	—
		Inoculated 3	—	—	—	1	—	—
		Inoculated 4	—	—	—	1	—	—
	60	Control.....1	—	—	—	—	—	—
		Inoculated 2	—	1	1	—	—	+
		Inoculated 3	—	1	1	—	—	0
		Inoculated 4	—	1	—	1	—	—
28	40	Control.....1	—	—	1	1	+	—
		Inoculated 2	—	—	—	—	—	—
		Inoculated 3	—	3	2	3	+	+
		Inoculated 4	—	—	—	—	—	—
	60	Control.....1	—	—	—	1	—	—
		Inoculated 2	—	—	—	1	—	—
		Inoculated 3	—	—	—	1	—	—
		Inoculated 4	—	1	1	1	—	+
32	40	Control.....1	—	—	—	1	0	—
		Inoculated 2	—	—	—	2	+	—
		Inoculated 3	no	germination				
		Inoculated 4	—	—	1	2	+	—
	60	Control.....1	—	—	—	—	—	—
		Inoculated 2	—	1	1	1	—	+
		Inoculated 3	—	—	—	1	+	—
		Inoculated 4	—	—	—	1	+	—
		Control.....1	—	—	—	—	—	—

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The results of this experiment are not as clear-cut and conclusive as those of Experiment 1. The per cent of infection was not as high; and while 30° was found to be the optimum soil temperature for the disease in Experiment 1, no positive wilting occurred at either 28° or 32° C. in this experiment. It is to be remembered that Early Ohio seed was used in this experiment while Irish Cobbler seed was used in Experiment 1. The results indicated that low soil moistures thruout the experiment were not favorable for the production of the wilt. This experiment was the first one in which plants were grown successfully at 36°, and while the plants grew and the amount of infection was greatest at this temperature, the appearance of the plants, especially of the root system, was very abnormal and neither the type of plant growth nor the conditions under which they were grown are comparable with natural field conditions.

EXPERIMENT 4, MARCH 3 TO MAY 12, 1921

This experiment differed from Experiment 3 in that higher soil moistures were used and no plants were kept at a constant temperature of 36°C. In the previous experiments the percentage of germination at this high temperature was very low and when germination took place the resulting plants were usually very abnormal and the unnatural growth increased the difficulty of recognizing the symptoms of the disease. In order to obviate this and also to study the effect of changing soil temperatures, the plants growing at 18° and 36° were alternated.

Methods.—Two different soil moistures were used. The moisture holding capacity of the soil determined by the 25 cm. cup method was 35 per cent dry weight. One-half of the cans were held at 60 per cent of the moisture holding capacity (21 per cent dry weight), which was the same as the highest moisture content in Experiment 3. The other half were held at 80 per cent of the moisture holding capacity (28 per cent dry weight). In order to prevent the drying out of the upper 2 inches of soil, the moisture content was kept constant by both subsoil and surface watering for several days previous to planting. Immediately after planting, the soil in each container was covered with 900 grams of crushed rock.[1] The same soil temperatures were used in Experiment 3 except at 36°C. One set of 8 plants was started at 18° soil temperature, and when the plants were about 3 to 6 inches tall at the end of 25 days and apparently healthy, they were changed to a soil temperature of 36° and remained at this temperature during the rest of the experiment. In the same way, one set of 8 plants was started at 36° and at the end of 25 days none of these plants were above ground. They were then removed to a

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in the same way as for Experiment 3 and tubers were used from the same source and treated in the same way. Just previous to planting, the soil was inoculated with cultures of *Fusarium oxysporum* No. 35 grown on rice. The containers were placed at the desired temperatures immediately after planting. The soil temperatures were taken at a depth of 3 inches 3 times daily and did not vary more than 1° from the desired temperature except in one set.[1] The air temperature was kept at approximately 18° except during the last few weeks of the experiment, when it sometimes rose to 25° during the middle of the day.

Results.—The plants started at 18° and changed to 36°C. were so badly wilted that they were dug and examined on May 2; the remainder of the plants were all dug on May 12. The results of the experiment are tabulated in Table 8. It was noticeable that at all the temperatures used many of the plants showed a yellowing and wilting of the lower leaves at various times during the experiment and later recovered and when examined at digging time were found to be healthy. Such plants are not listed in the table as diseased. The quick change of soil temperature with the plants started at 18° and changed to 36° resulted in a rapid wilting and drying of the lower half of the plant. After about one week, however, these leaves dropped off, the plants, apparently becoming adapted to the high temperature, appeared perfectly healthy, and later the disease appeared and wilting became complete in some cases.

At 18°C. no definite wilting was observed except in the case of one control that wilted from other causes. No wilt occurred at 24° except in one control plant. Four plants, 2 at each soil moisture, showed either slight stem rot or slight root injury. At 28° one plant wilted and one other plant showed definite signs of the disease in the underground portion. At 32° the results do not agree with the previous experiments; practically no infection was found, only 2 of the plants showing a slight rotting at the base of the stem. The plants started at 18° and changed to 36° showed a marked difference from the plants at the other temperatures. All of these, including the controls, showed wilt symptoms. The vascular system of the stem of both controls was slightly discolored but no root infection or stem rot was present and cultures from the stem were sterile. This slight discoloration of the stem was evidently due to the extremely high soil temperature just previous to digging, as previously mentioned. The inoculated plants started to wilt about April 25,

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TABLE 8.—*Relation of soil temperature and moisture to infection of Early Ohio potatoes from soil inoculated with Fusarium oxysporum No. 35*

Experiment 4

Soil temperature	Soil moisture[1]	Treatment of plants	Symptoms				Cultures of *F. oxysporum*	
			Wilt	Vascular discoloration	Stem rot	Root injury	From roots	From stems
Degrees C.	*Per cent*	Control.....1	—	—	—	—	—	—
		Inoculated 2	—	—	—	—	—	—
	60	Inoculated 3	—	—	—	—	—	—
		Inoculated 4	—	—	—	1	—	—
18		Control.....1	3	—	—	—	—	—
		Inoculated 2	—	—	—	1	—	—
	80	Inoculated 3	—	—	—	1	—	—
		Inoculated 4	—	—	—	—	—	—
		Control.....1	—	—	—	—	—	—
		Inoculated 2	—	—	1	—	—	—
	60	Inoculated 3	—	—	—	1	—	—
		Inoculated 4	—	—	—	—	—	+
24		Control.....1	2	2	2	2	—	+
		Inoculated 2	—	—	—	1	+	—
	80	Inoculated 3	—	—	—	1	—	—
		Inoculated 4	—	—	—	—	—	—
		Control.....1	—	—	—	—	—	—
		Inoculated 2	—	—	—	—	—	—
	60	Inoculated 3	—	2	2	1	—	+
28		Inoculated 4	—	—	—	—	—	—
		Control.....1	—	—	—	—	—	—
		Inoculated 2	—	1	—	—	—	—
	80	Inoculated 3	1	1	1	1	—	+
		Inoculated 4	—	—	1	—	—	—
		Control.....1	—	—	—	—	—	—
		Inoculated 2	—	—	—	—	—	—
	60	Inoculated 3	—	—	—	—	—	—
32		Inoculated 4	—	—	1	—	—	—
		Control.....1	—	—	—	—	—	—
		Inoculated 2	—	—	—	—	—	—
	80	Inoculated 3	—	—	—	—	—	—
		Inoculated 4	—	—	1	—	—	—
		Control.....1	1	1	—	—	—	0
		Inoculated 2	1	2	1	3	+	+
	60	Inoculated 3	3	3	3	3	+	+
18[2] to 36		Inoculated 4	1	1	—	1	+	—
		Control.....1	1	1	—	—	—	0
		Inoculated 2	3	3	3	3	+	0
	80	Inoculated 3	3	3	3	3	+	+
		Inoculated 4	3	3	3	3	0	0
		Control.....1	—	—	—	—	—	—
		Inoculated 2	—	—	—	—	—	—
	60	Inoculated 3	no	germination				

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capacity were completely wilted by May 2, while 1 plant was completely wilted and 2 slightly wilted in the set at 40 per cent moisture. All of these inoculated plants showed definite signs of disease below ground and the causal organism was recovered from either roots or stems in all but one instance. As previously noted, the plants started at 36° were not above ground when the soil temperature was changed to 18°. At the latter temperature, all plants that grew remained healthy.

The only temperature at which uniform results were secured in this experiment was with plants started at 18° and changed to 36°C. In these plants the wilting symptoms and the vascular discoloration of the stem were undoubtedly due in part directly to the high soil temperature as indicated by the controls. In this set the infection appeared to be greater in soil kept at 80 per cent rather than at 60 per cent of the moisture holding capacity.

The effect of wilting due to high temperature with subsequent recovery shows that it is difficult to examine a plant having slight signs of wilt during an experiment either in the field or under control conditions and attempt to determine whether these slight symptoms of disease are due to environmental conditions or to some wilt producing parasite.

EXPERIMENT 5. NOVEMBER 22, 1921, TO FEBRUARY 20, 1922

This experiment was planned to test the pathogenicity of *Fusarium oxysporum* as a soil parasite when both soil temperatures and soil moistures are changed during the course of the experiment.

Methods.—Healthy tubers of the Bliss Triumph variety were used. They were cut and sprouted in moist sand. The sprouts were ¼ inch long when planted and the cut surface was well calloused over. The soil was mixed the same as in the previous experiment and was sterilized for 3 hours at 2½ pounds pressure. It was then inoculated previous to planting with cultures of *Fusarium oxysporum* No. 35 grown on Melilotus stems. The moisture content of the soil at the start of the experiment was 20.4 per cent dry weight. This was 60 per cent of the moisture holding capacity, previously determined to be 34 per cent dry weight. The soil was kept at the desired moisture content as in Experiment 4. All the contain-

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showed the temperature of the soil in the various sets at the depth of 3 inches to average 23.6°, 27.7°, 27.9°,30.6°, and 35.7° C.

On January 3 all the plants growing in tanks at 24°, 28°, 32°, and 36° were transferred to room temperature (18° C.). Thirty-two of the plants that had been growing at (18°) room temperature were transferred to 24°, 28°, 32°, and 36° tanks. One set of 8 plants was allowed to remain in the second 28° tank thruout the experiment and another set was left at (18°) room temperature thruout the experiment. At the time the temperatures were changed, January 3, the soil moisture of half of the plants in each set, 3 inoculated and 1 control, was allowed to drop to 13.6 per cent dry weight, or 40 per cent of the moisture holding capacity; the other half of each set remaining at 60 per cent of the moisture holding capacity.

Results.—All plants were examined almost daily and the notes taken are represented briefly in Tables 9a and 9b with the final notes taken at digging time.

At the time the temperatures were changed (January 3) all the plants growing at 18°C. (room temperature) were in a healthy, vigorous condition. The plants in the tanks were all healthy and vigorous except at 32° and 36°, where the high soil temperature caused rather small, weak, spindling plants. When these plants were changed to 18° they gradually lost this appearance, and at the end of the experiment were apparently not suffering from this previous exposure to a high soil temperature. Likewise, the plants changed from 18° to 32° and 36° turned yellow and wilted considerably during the first 2 weeks, but after losing their lower leaves growth was renewed and the controls showed no signs of wilting at the close of the experiment. The effect of the dropping of the soil moisture content from 60 to 40 per cent of the moisture holding capacity of the soil was apparent in a drooping and wilting of the leaves. This was not accompanied by any yellowing, however, and the plants usually recovered from the change in the soil moisture in less than 2 weeks. Only 3 control plants out of 20 in the experiment showed any wilt. Isolations were made from both stems and roots of these control plants, and *Fusarium oxysporum* was not recovered in any instance.

The greatest amount of infection occurred at the constant temperature of 28°C. There was severe wilting of all plants, accompanied by a vascular discoloration and considerable root injury and isolations revealed the presence of *Fusarium oxysporum* in every plant. There was no apparent difference in the amount of wilt at this temperature with different soil moisture contents. The next greatest amount of wilting occurred in the plants grown at 18° and changed to 32° and 36° with 40 per cent

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TABLE 9a.—*Relation of varying soil temperatures and moistures to the infection of Bliss Triumph potatoes from soil inoculated with Fusarium oxysporum. No. 35*

Experiment 5

Soil moisture[1]	Temperature	Treatment of plants	Symptoms				Cultures of *F. oxysporum*	
			Wilt	Vascular discoloration	Stem rot	Root injury	From roots	From stems
Per cent	*Degrees C.*							
	18			All plants healthy				
		Control.....1	—	1	—	1	—	0
		Inoculated 2	—	1	—	1	—	0
	18 to 24	Inoculated 3	—	—	—	—	—	—
		Inoculated 4	—	—	—	—	—	—
		Control.....1	—	1	—	—	—	0
		Inoculated 2	—	—	—	—	—	—
	18 to 28	Inoculated 3	—	1	—	—	—	—
		Inoculated 4	—	—	—	1	—	—
		Control.....1	—	1	—	1	0	—
		Inoculated 2	2	—	—	—	—	—
	18 to 32	Inoculated 3	3	1	—	2	+	+
		Inoculated 4	—	—	—	—	—	—
		Control.....1	—	3	—	1	0	0
		Inoculated 2	3	3	3	3	dead	dead
	18 to 36	Inoculated 3	3	1	—	1	0	0
		Inoculated 4	—	—	—	—	—	—
60 to 40		Control.....1	—	—	—	—	—	—
		Inoculated 2	—	—	—	—	—	—
	36 to 18	Inoculated 3	—	3	3	1	—	+
		Inoculated 4	—	—	—	—	—	—
		Control.....1	—	1	—	—	—	—
		Inoculated 2	—	—	—	—	—	—
	32 to 18	Inoculated 3	—	1	—	1	+	—
		Inoculated 4	—	1	—	1	+	+
		Control.....1	3	3	—	1	0	0
		Inoculated 2	—	—	—	—	—	—
	28 to 18	Inoculated 3	—	3	—	1	0	—
		Inoculated 4	—	—	—	—	—	—
		Control.....1	—	—	—	—	—	—
		Inoculated 2	—	—	—	—	—	—
	24 to 18	Inoculated 3	—	—	—	—	—	—
		Inoculated 4	—	1	—	—	0	+
		Control.....1	3	3	—	3	0	0
		Inoculated 2	1	3	2	3	+	+
	28	Inoculated 3	3	3	—	2	+	+
		Inoculated 4	3	3	—	3	0	+

[1] Soil moistures are expressed in per cent of the moisture holding capacity (34

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TABLE 9b.—*Relation of varying soil temperatures and moistures to the infection of Bliss Triumph potatoes from soil inoculated with Fusarium oxysporum No. 35*

Experiment 5

Soil moisture[1]	Temperature	Treatment of plants	Symptoms				Cultures of *F. oxysporum*	
			Wilt	Vascular discoloration	Stem rot	Root injury	From roots	From stems
Per cent	*Degrees C.*							
	18			All plants healthy				
	18 to 24	Control.....1	—	1	—	1	0	0
		Inoculated 2	—	3	—	2	0	+
		Inoculated 3	—	3	—	1	0	+
		Inoculated 4	—	—	—	—	—	—
	18 to 28	Control.....1	—	1	—	—	—	+
		Inoculated 2	1	3	2	3	—	● 0
		Inoculated 3	1	—	—	—	—	—
		Inoculated 4	—	3	1	1	0	0
	18 to 32	Control.....1	—	—	—	—	—	—
		Inoculated 2	—	3	—	2	+	+
		Inoculated 3	—	2	3	3	0	0
		Inoculated 4	—	—	—	—	—	—
	18 to 36	Control.....1	—	1	—	2	0	+
		Inoculated 2	—	3	2	2	0	0
		Inoculated 3	—	—	—	1	0	—
60 to 60		Inoculated 4	—	3	—	2	+	+
	36 to 18	Control.....1	—	2	1	1	—	0
		Inoculated 2	—	—	—	—	—	—
		Inoculated 3	—	—	—	—	—	—
		Inoculated 4	—	—	—	—	—	—
	32 to 18	Control.....1	—	—	—	—	—	—
		Inoculated 2	—	—	—	—	—	—
		Inoculated 3	—	—	—	—	—	—
		Inoculated 4	—	3	—	2	+	+
	28 to 18	Control.....1	—	—	—	—	—	—
		Inoculated 2	—	—	—	1	—	—
		Inoculated 3	—	—	—	—	—	—
		Inoculated 4	—	2	—	1	0	0
	24 to 18	Control.....1	—	—	—	—	—	—
		Inoculated 2	—	—	—	—	—	—
		Inoculated 3	—	—	—	—	—	—
		Inoculated 4	—	—	—	—	—	—
	28	Control.....1	3	2	—	2	0	0
		Inoculated 2	2	3	—	3	+	+
		Inoculated 3	1	3	3	3	+	0
		Inoculated 4	3	3	2	3	+	+

[1] Soil moistures are expressed in per cent of the moisture holding capacity (34 per cent dry weight).

There was a very slight amount of disease present in the plants grown at (18° to 24°) and (24° to 18°). No wilting occurred

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in any of the inoculated plants changed to 18° on January 3 altho vascular discoloration was present in a number of plants and the causal organism was isolated in pure culture.

Isolations were made from practically all the plants showing wilting accompanied by vascular discoloration or considerable root injury. One plant at (18° to 36°C.) was so badly decayed that isolations were impractical. In most cases 4 tissue cultures were made from each specimen. If any of these showed *Fusarium oxysporum* the cultures were marked in the table as positive. From 28 plants with diseased roots, *F. oxysporum* was isolated 11 times, or 39 per cent. Cultures from the stems of 32 plants yielded *F. oxysporum* 16 times or 50 per cent. Fifteen plants showed complete or nearly complete wilt. *F. oxysporum* was isolated from only 7 of them. Two of these 15 plants showed no vascular discoloration or root injury and the other 6 yielded various species of Fusaria, but not *F. oxysporum*. Slight yellowing of the lower leaves even when accompanied by slight wilting appears to have no value in estimating the amount of infection.

The chief difference in the effect of changing the soil moisture at the time the temperatures were changed appeared to be in the greater amount of stem rot and the smaller amount of wilt with the higher soil moisture. The extent of root injury was greater on infected plants at the higher moisture content altho there was only one more plant showing root injury than at the low moisture.

There was undoubtedly some vascular discoloration, either accompanying positive wilting symptoms or without any signs of wilt, that was not caused by *Fusarium oxysporum*. Cultures made from 20 plants showing vascular discoloration accompanied by wilt yielded *F. oxysporum* only 10 times; and 12 plants showing vascular discoloration and with no wilt yielded *F. oxysporum* only 6 times. Thus, the causal organism was isolated from only 50 per cent of the plants. Neither vascular browning nor wilting of the tops is a sure index of the presence of *F. oxysporum*.

EXPERIMENT 6, FEBRUARY 13 TO MAY 11, 1922

This experiment differs from the previous soil temperature experiment in that the soil used was not sterilized and the freshly cut seed tubers were dipped in a water suspension of spores just previous to planting. The soil was also inoculated as in the

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was planned in order to eliminate such possible injury. The seed-piece as well as the soil was inoculated in an attempt to produce a type of infection similar to that reported by MacMillan (1919). Infection thru the seed-piece from the soil did not appear to any extent in the previous experiments when the soil was heavily inoculated, so this experiment was planned with a direct inoculation of the freshly cut seed-piece as well as soil inoculation.

Methods.—The soil was mixed as in the previous experiments and inoculated with cultures of *Fusarium oxysporum* No. 35 grown on boiled rice and Melilotus stems. The seed tubers used were from the same lot as those in Experiment 5. The freshly cut seed-pieces were dipped in a water suspension of spores similar to the inoculum used for the soil. The soil moisture was held at 26.3 per cent dry weight. This was 70 per cent of the moisture holding capacity, previously determined to be 37.6 per cent dry weight. Immediately after planting, all cans were removed to the desired temperatures. The cans were watered thruout the experiment by surface and subsoil watering. The surface of the soil was covered with crushed rock. Six inoculated and 2 control cans were used at each of the following temperatures, 18°, 24°, 28°, 32°, and 36°C. Temperature records showed the temperature in the various sets to average as follows: 17.9°, 24.1°, 28.2°, 32.0°, and 34.7°. The air temperature was held at 18° at the start, but during the latter half of the experiment it often reached 25° during the day.

Results.—Altho we would expect a greater amount of infection in this experiment than in Experiment 5, due to the direct inoculation of freshly cut seed, Table 10 shows a very small percentage of positive inoculations. The 2 experiments were run for the same length of time and inoculum from the same strain of Fusarium was used. Potato seed from the same source was used in both experiments, but the seed in this experiment was about 3 months older than in Experiment 5. At the close of the experiment, only one typical case of wilt due to infection with *Fusarium oxysporum* was found. In general, there was considerable drying and yellowing of the leaves, due to the rather high air temperature toward the close of the experiment. The plants at 18°C. were the most vigorous in the experiment. The greatest difference between inoculated and control plants was found in the few plants grown at 32°. The only positive case of wilt occurred at 28°. In general, the controls showed as much infection as the inoculated plants. This was probably due to the fact that the soil was not sterilized. Three control plants and only 2 inoculated plants showed vascular discoloration of the underground stem, altho the infection appeared deeper in the inoculated ones than in the controls. Three controls and 4 inoculated plants showed root injury, and again the injury appeared greatest in the in-

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TABLE 10.—*Relation of soil temperature to infection of Bliss Triumph potatoes when both soil and seed were inoculated with Fusarium oxysporum No. 35*

Experiment 6[1]

Temperature	Treatment of plants		Symptoms				Cultures of *F. oxysporum*	
			Wilt	Vascular discoloration	Stem rot	Root injury	From roots	From stems
Degrees C.								
18	2 controls, 6 inoculated plants, all healthy							
24	Control	1	—	2	—	2	+	+
		2	—	1	—	2	+	+
	Inoculated	3	—	—	—	—	—	—
		4	—	—	—	—	—	—
		5	—	—	—	—	—	—
		6	—	—	—	—	—	—
		7	—	—	—	—	—	—
		8	—	—	—	1	—	—
28	Control	1	—	1	—	2	+	+
		2	—	—	—	—	—	—
	Inoculated	3	—	—	—	2	—	—
		4	—	—	—	1	—	—
		5	—	—	—	—	—	—
		6	—	—	—	—	—	—
		7	3	3	2	3	+	+
		8	—	—	—	—	—	—
32	2 controls and 5 inoculated plants failed to germinate							
	Inoculated	8	—	2	2	3	+	+
18[2] to 32	Control	1	—	—		—	—	—
	Inoculated	2	—	—		2	—	—
36	2 controls and 6 inoculated plants failed to germinate							

[1] The moisture content of the soil was kept at 70 per cent of the moisture holding capacity or 26.3 per cent dry weight.

[2] These two plants had been growing at 18° and were placed at 32°C. on March 22 to replace seed that failed to germinate.

oculated ones. Cultures of *F. oxysporum* were obtained from all plants showing vascular browning of the underground stem.

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Effect of High Soil Temperature on the Potato Plant

Two plants inoculated with *Fusarium oxysporum* and 1 control plant grown in the 18° tank with an air temperature of about 18°C. were found to be healthy at the end of the experiment. These plants were left in the tanks and were submitted to the extreme soil temperature of about 60° for one hour and then brought back to 18° and left at this temperature for 2 weeks. All 3 plants when dug showed a distinct vascular browning, appearing very similar to the vascular browning caused by *F. oxysporum*. The tissue of the underground portion of the stem was softened and slightly rotted both in the inoculated and in the control plants. The roots were slightly injured. Cultures from the browned vascular system were sterile. This would indicate that we might expect vascular browning from other causes than *F. oxysporum* infection, and that this browning is rather a poor criterion for pronouncing the plant to be infected with *F. oxysporum* unless it is considered along with other symptoms. While the temperature used was extremely high, it is very probable that the same results may be obtained by using a lower temperature with a longer or intermittant exposure.

Effect of High Air and Soil Temperature on the Disease

Six pots, 4 with inoculated soil and 2 controls, were planted at the same time as Soil Temperature Experiment 1. Similar soil and seed and the same methods were used for the inoculations. These pots were kept in a greenhouse maintained at the approximate temperature of 25°C. until they were all about 6 inches high with a good even growth and no signs of disease. They were then removed to a high temperature greenhouse (30°-33°). Ten days after being changed to this high temperature the infected plants were badly yellowed and wilted; the controls were slightly wilted. Ten days later, all the plants were entirely wilted. The controls, altho entirely dead above ground, showed no signs of disease in the underground parts, the stems, roots and stolons being healthy. *Fusarium oxysporum* was recovered from the rotted underground portion of the stems of the inoculated plants.

It was very probable that infection had already set in before these plants were removed to the high temperature and that this high temperature simply favored the rapid advance of the disease. It is noticeable, however, that altho the roots and stems of the control plants remained healthy the tops wilted rapidly, and the above-ground symptoms could not be used in identifying the presence of the organism.

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Relation of Soil Moisture to Infection of Roots from the Soil

EXPERIMENT 1, DECEMBER 11, 1920, TO MARCH 11, 1921

In the previous experiments with controlled soil temperatures it was found that the soil moisture content was also a factor in determining the amount and severity of infection and that a change in the soil moisture during the experiment affected the results. The extent of the influence of soil moisture was rather hard to determine, as the soil temperatures were also varied in these experiments. The following experiment was planned to test the effect of varying soil moisture contents upon the disease when the soil and air temperature remained approximately constant.

Methods.—The experiment was conducted in a greenhouse maintained at a temperature of approximately 25°C. Seed tubers of the Early Ohio variety were used from the same lot as those used in Soil Temperature Experiment 3, and were treated in the same way. Soil was prepared in the same way as for the soil temperature experiments. Four-gallon earthenware crocks were used for containers, each holding 16,650 grams of soil, dry weight. The soil was inoculated just previous to planting with cultures of *Fusarium oxysporum* No. 35. Two seed tubers were planted in each container. The soil moisture was maintained by watering methods similar to those used in the soil temperature experiments. One thousand grams of crushed rock was used on the surface of the soil. The moisture holding capacity of the soil as determined by the 25 cm. cup method was 35 per cent dry weight. Twenty-seven containers were used, being divided into 3 sets, each set composed of 3 controls and 6 inoculated pots. The soil in these 3 sets of 9 containers each was started at approximately 40, 60, and 80 per cent of the moisture holding capacity of the soil, equal to 14, 21, and 28 per cent dry weight, respectively. The soil after inoculation was brought up to the desired moisture content in each set and allowed to stand about 10 days before planting. The soil moisture content in each of these sets was changed on January 8 by dividing each set into 3 lots of 1 control and 2 inoculated containers each. Thus, in Set 1, 9 containers (at 40 per cent of moisture holding capacity) were divided into 3 lots. Three containers were left at 40 per cent, 3 changed to 60 per cent, and 3 to 80 per cent of the moisture holding capacity of the soil. In the same way, the sets being held at 60 and 80 per cent were each subdivided into 3 lots. In changing the moisture contents, if the desired point was higher, water was added at the rate of 500 c. c. per day until the desired point was reached. If a lower moisture content was wanted, the soil was allowed to dry out naturally until the desired moisture content was reached. The maximum change, that is, from 40 to 80 per cent of the moisture holding capacity or vice versa, took place in approximately 10 days. From 40 to 60 per cent or 60 to 80 per cent took about one-half this time. Weighings were made and the moisture contents calculated for each day while changing, but as the slight variation in the length of time necessary to change the moisture content did not appear to be correlated with any of the final results, the figures are not presented here. On February 15 the moisture contents of the 9 lots were changed back to the original moisture content of the 3 sets.

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TABLE 11.—*Relation of soil moisture to infection of Early Ohio potato plants from soil inoculated with Fusarium oxysporum No. 35*

Experiment 1 [1]

Soil moisture[2]	Treatment of plants	Symptoms				Cultures of *F. oxysporum*	
		Wilt	Vascular discoloration	Stem rot	Root injury	From roots	From stems
Per cent							
	Control.....1	—	—	—	—	—	—
40	Inoculated..2	—	—	—	—	—	—
	Inoculated..3	—	—	1	1	+	+
40 to	Control.....1	—	—	1	1	—	+
60 to	Inoculated..2	3	3	3	3	+	+
40	Inoculated..3	2	1	—	1	+	+
40 to	Control.....1	1	2	1	1	—	—
80 to	Inoculated..2	1	3	1	3	—	+
40	Inoculated..3	2	3	3	3	+	+
	Control.....1	—	—	—	—	—	—
60	Inoculated..2	—	1	—	—	—	+
	Inoculated..3	—	—	1	1	—	+
60 to	Control.....1	—	—	—	—	—	—
40 to	Inoculated..2	1	—	—	1	—	—
60	Inoculated..3	—	1	1	—	—	+
60 to	Control.....1	—	—	—	—	—	—
80 to	Inoculated..2	—	3	3	—	—	+
60	Inoculated..3	—	—	1	—	—	+
	Control.....1	1	—	—	—	—	—
80	Inoculated..2	1	2	2	1	—	+
	Inoculated..3	—	—	—	—	—	—
80 to	Control.....1	1	—	—	—	—	—
60 to	Inoculated..2	1	3	3	—	—	+
80	Inoculated..3	—	1	—	—	—	+
80 to	Control.....1	—	—	1	1	—	+
40 to	Inoculated..2	—	—	—	—	—	—
80	Inoculated..3	2	2	3	—	—	+

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Results.—The results of this experiment are shown in Table 11. The germination of the seed was very uniform, altho the plants started at 40 per cent of the moisture holding capacity were a little slower in breaking thru the ground. On January 8, when the soil moistures were first changed, all the plants were healthy altho the size varied with the moisture content of the soil, those growing at 40 per cent averaging about 2.5 inches in height, those at 60 per cent, 4 inches, and those at 80 per cent, 4.5 inches. The change in soil moistures, where the moisture content was lowered, was sometimes followed by a drooping of the leaves, but the plants recovered quickly and were apparently normal in about 10 days, the time used in reaching the new moisture content. On February 15, when the moisture contents were again changed, no definite wilting had occurred in any of the plants, altho there was a slight yellowing of the lower leaves in all sets, this being more marked in the 40 per cent set than at the higher moisture contents. At the higher moistures, however, the plants were not as sturdy, the tops often drooping over. At the close of the experiment it was found that the underground stems of the plants at 80 per cent were much smaller in diameter than those at the lower moisture contents. As shown in Table 11, the sets held at a constant moisture content showed less infection than those in which the moisture content was changed. The smallest amount of infection occurred at the constant moisture content of 40 per cent while the largest amount occurred at 80 per cent. The reverse is true, however, in regard to the pots in which the moisture content was varied. The largest amount of wilt along with the heaviest infection of stem and roots occurred in the (40 to 80 to 40) per cent lot, and the next in the (40 to 60 to 40) per cent lot. There was not a great deal of difference between the other sets, altho there appeared to be slightly more stem infection in the 80 per cent lots than in the 60 per cent lots. Three of the control plants showed symptoms of the disease but *Fusarium oxysporum* was isolated successfully from only one of them. Cultures from the inoculated plants showing symptoms of disease yielded *F. oxysporum* from either the stems or the roots in every instance.

EXPERIMENT 2, DECEMBER 5, 1921, TO FEBRUARY 20, 1922

This experiment was planned somewhat similarly to Soil Moisture Experiment 1, except that a different variety of potatoes was used and the soil moistures were changed once, and were not brought back to the original soil moisture content as in Experiment 1.

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Methods.—Tubers of the Bliss Triumph variety were used from the same lot as those used in Soil Temperature Experiment 5. They were treated in the same way, except that immediately before planting the cut surfaces which had calloused over while the sprouts were starting were freshly cut and planted in soil that had been inoculated at the same time and in the same way as for Soil Temperature Experiment 5. The tubers were planted in 3-gallon stone crocks, one seed-piece to each crock which contained 12 kilograms of soil with 1,000 grams of gravel added to the surface. The soil was watered as in the previous experiment. All the pots were filled with soil and allowed to stand for 2 weeks before planting. During this time the moisture content of the soil was brought up to the desired point. Thirty-six crocks were used in the experiment, being divided at the start into 3 sets, each having 9 inoculated and 3 control crocks. These 3 sets were held at 3 different soil moisture contents, as indicated in Table 12. The moisture holding capacity of the soil was 34 per cent dry weight determined by the 25 cm. cup method. Set 1 was held at 40 per cent of the moisture holding capacity (12.1 per cent dry weight); set 2 at 60 per cent (20.4 per cent dry weight); set 3 at 80 per cent (27.2 per cent dry weight). When the plants were about 6 inches in height, January 9, the soil moisture was changed, so that each set was divided up into 3 lots, each with 3 inoculated and 1 control plant, the same as in the previous experiment. The entire experiment was run in a greenhouse where thermograph records showed the average daily maximum temperature to be 80.5°F. (26.9°C.), the average daily minimum at 71.5°F. (21.9°C.), and the average daily mean temperature 75.5°F. (24.2°C.).

In order to check the possible error in the percentage of soil moisture in the different sets, 2 samples were taken from each of 3 crocks labeled 40, 60, and 80 per cent of moisture holding capacity. These showed the following errors to be present at the end of the experiment in the pots tested:

40 per cent = 12.1 per cent dry weight, at close of experiment was 41.1 per cent or 14 per cent dry weight.

60 per cent = 20.4 per cent dry weight, at close of experiment was 60.5 per cent or 20.6 per cent dry weight.

80 per cent = 27.2 per cent dry weight, at close of experiment was 70.0 per cent or 23.8 per cent dry weight.

This showed practically no error in the crocks at 40 and 60 per cent of the moisture holding capacity, but a considerable drop in the 80 per cent set. This was probably due to the increased weight of the plant which was not taken into account in the watering and which in the 40 to 60 per cent sets seemed to be about balanced by the decrease in the moisture holding capacity of the soil due to packing during the experiment.

Results.—All plants were dug and examined February 20,

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died at 40 per cent moisture in Set 1, but this appeared to be due to causes other than *Fusarium oxysporum.*

As in the previous experiment, the plants were about one week slower in breaking thru the ground at 40 per cent than at the higher moisture contents. When the soil moistures were changed, all the plants in the experiment were apparently healthy and averaged about 6 inches in height. At the close of the experiment all plants showed a slight yellowing and drying of the

TABLE 12.—*Relation of soil moisture to infection of Bliss Triumph potatoes from soil inoculated with Fusarium oxysporum No. 35*

Experiment 2

Soil moisture[1]		Treatment of plants	Symptoms				Cultures of *F. oxysporum*	
			Wilt	Vascular discoloration	Stem rot	Root injury	From roots	From stems
Per cent								
	40	Control.....1	—	1	—	—	—	0
		Inoculated..2	—	—	—	—	—	—
		Inoculated..3	—	—			0	0
		Inoculated..4	—	—	—	—	—	—
40	60	Control.....1	—	—	—	—	—	—
		Inoculated..2	—	—	—	—	—	—
		Inoculated..3	—	1	—	1	+	+
		Inoculated..4	—	—	—	—	—	—
	80	Control.....1	—	1	—	—	—	0
		Inoculated..2	—	—	—	—	—	—
		Inoculated..3	—	—	—	—	—	—
		Inoculated..4	—	—	—	—	—	—
	40	Control.....1	—	—	—	—	—	—
		Inoculated..2	—	2	2	1	0	+
		Inoculated..3	—	1	—	1	—	—
		Inoculated..4	—	—	—	—	—	—
60	60	Control.....1	—	—	—	—	—	—
		Inoculated..2	—	1	—	—	—	—
		Inoculated..3	—	—	—	—	—	—
		Inoculated..4	—	—	—	—	—	—
	80	Control.....1	—	—	—	—	—	—
		Inoculated..2	—	—	—	—	—	—
		Inoculated..3	—	1	—	—	—	0
		Inoculated..4	1	—	—	—	—	—
	40	Control.....1	—	—	—	—	—	—
		Inoculated..2	—	1	—	1	+	+
		Inoculated..3	—	—	—	—	—	—
		Inoculated..4	—	—	—	—	—	—
80	60	1 control, 3 inoculated healthy						

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lower leaves not associated with the disease. There were no marked differences between the various sets. Only one plant showed any wilting symptoms and this was not due to Fusarium infection.

It is worthy of note that altho this experiment was conducted at a temperature averaging about 25° and the same inoculated soil, and seed from the same source as that of Soil Temperature Experiment 5 was used, the amount of infection was considerably less than that obtained in the Soil Temperature Experiment at a constant temperature of 28°C., where the greatest amount of infection took place.

It is also noticeable that in this experiment where the soil was heavily infested the seed tubers were planted with a freshly cut surface exposed for infection and at a temperature and soil moisture higher than that found under ordinary field conditions, and yet no results were obtained that were remotely comparable with those reported by MacMillan (1919) for soil infection thru the seed-pieces under field conditions.

DISCUSSION

These experiments, conducted with as many environmental factors under control as was possible and with inoculations with various strains of *Fusarium oxysporum*, show the usual confusion of results. It was impossible to obtain consistent results in consecutive experiments and in most cases the percentage of infection was rather low. It was evident, however, that temperatures of 18°C. and below were unfavorable for the development of the disease and that in general the amount of infection increased with increasing soil temperatures. It was noticeable that under these conditions the disease developed most readily at temperatures unfavorable for the host plant. Plants started at a temperature low enough to be unfavorable for the disease but later transferred to a higher temperature showed nearly as much disease as those kept at a constant high temperature; while those started at high temperatures and later transferred to lower temperatures showed practically no disease, as did those kept at a constant low temperature.

Constant low soil moistures were unfavorable for the development of the disease. However, when the soil moisture content was varied it was found that the disease developed best when the plants were started at a low soil moisture content, changed to high soil moistures during the critical period in the life of the plant, and later lowered to the original low soil moisture content.

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It was also noticeable in all these tests that with increasing soil moisture the amount of rotting of the roots and stems increased and the wilting symptoms were not as marked as at the lower soil moistures. It was also shown that there was often present a discoloration of the vascular system of the main stem, either in the absence of wilt or accompanying these symptoms, that was not caused by *Fusarium oxysporum*. If the plants were submitted to extremely high temperatures for relatively short intervals, a vascular discoloration was produced that had all the aspects of Fusarium infection.

It is also worthy of note that in all these infection tests no correlation could be made between the presence of the disease and the rotting of seed-pieces. Where infection took place, it was thru the roots and not thru the seed-pieces. In all of these tests, the seed-pieces behaved alike both in the controls and in the inoculated plants.

INFECTION FROM THE SOIL THRU THE SEED-PIECE

Review

In all the published work on Fusarium wilt previous to 1919, the emphasis was placed upon the infection of the plant from the soil thru the roots or by the planting of infected seed. Infection of the plant from the soil thru the seed-piece was not recorded until MacMillan's (1919) publication. This may very probably be accounted for as MacMillan suggests (p. 280):

> Since the part of Fusarium spp. in the creation of disease depends largely on environmental factors, it is important to note that the conditions which prevail in Colorado do not exist in the same way in other places. The descriptions of diseases caused by species of Fusarium already published do not, therefore, closely apply to Colorado, because the climate, coupled with the soil conditions and irrigation practice existing there, creates a condition unknown in the East, where most of the work on Fusarium spp. has been done.

The writer has found this statement to hold true not only as regards the different manifestations of the disease in the irrigated sections of western Nebraska as compared with previous observations in Michigan, but also as compared with dry land sections of western Nebraska. In other words, the type of infection appears to be due in a great measure to the environmental conditions and it is impossible to predict what will happen under irrigation in the West from experimental data obtained in the East or from dry land conditions in the West. It is not necessary, however, to have a different type of infection in order to produce

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different symptoms of disease; it is only necessary to have present different environmental conditions after infection has taken place. All 3 types of infection discussed in this paper have been found in Michigan as well as in the irrigated fields of Nebraska but the amount of each of these 3 types varied with the conditions present.

MacMillan reports experiments in which the seed tubers were inoculated with a spore suspension of *Fusarium oxysporum* and then planted either in flats or under field conditions, also by inoculating the seed-pieces of plants which had already sent up sprouts. He obtained nearly 100 per cent infection with this method of inoculation. He concludes from these experiments (p. 300):

> Two methods of infection are recognized: Infection from the soil of roots and root hairs, and infection of the seed-piece, whereby the plant becomes diseased. The latter method is regarded as the most serious and responsive to environmental conditions in the Greeley district of Colorado.

While he does not state the conditions under which his experiments were conducted as to temperature and moisture, he says in referring to the relation of soil temperature to infection (p. 299):

> Seed-piece infection will occur at a considerably lower temperature than root infection.

The author found that under the conditions prevailing in Michigan during the experiments previously discussed infection from the soil thru the seed-pieces occurred but rarely. It was found so seldom that it was not considered of any importance under those conditions. It might also be noted that in these experiments rotting of the underground stem was very rare, and in general, conditions were not favorable and probably are very seldom favorable in Michigan for this type of infection. In the numerous soil infection experiments conducted under controlled conditions, the seed-piece very often remained healthy thruout the experiment and in only a few cases could the infection be tracd to the seed tuber.

Greenhouse Experiments, 1920-21

In 1920 a few tests were made with artificially infected seed. Healthy Irish Cobbler potatoes were inoculated by placing a few drops of spore suspension in a small hole bored out of the tuber. It was then sealed with a cover glass and planted in sterilized soil. Three seed-pieces inoculated with *Fusarium oxysporum* No. 33 and grown in a greenhouse maintained at approximately 17°C. produced healthy plants with no signs of wilt. One seed-piece had rotted slightly and the base of one stem of this plant was slightly infected. In the other 2 the infection of the seed-piece

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progressed only a short distance beyond the point of inoculation and the seed remained attached to the stem when the plant was dug. Two seed-pieces were inoculated with *F. oxysporum* No. 8 and kept at the same temperature. Both plants were healthy, the seed-pieces being only slightly rotted. All these plants were duplicated in another greenhouse with a temperature maintained at approximately 27°. All plants remained healthy, and the seed-pieces were still attached, altho they had rotted considerably further than in the plants held at 17°.

During 1921, 16 tubers were inoculated in the same way with *Fusarium oxysporum* No. 35, and kept in a greenhouse at a temperature of 25°C. Half of these plants were watered as usual and the other half were given an excess of water. Only 1 plant showed wilt and this was in the heavily watered set. The seed-piece had completely decayed and the infection of the main stem started at the base and had resulted in a soft rot.

This method of infection was also tried in Soil Temperature Experiment 6, p. 58, where the freshly cut seed-pieces were dipped in a spore suspension just previous to planting, the soil also being inoculated.

Field Experiments, 1921

This method of infection was tested in 1921 under field conditions. The experiment was run in triplicate, three plots having different environmental conditions being used.

Location of plots.—Plot 1 was located at the Agricultural College, Lincoln, Nebraska. No potatoes had been grown on this land for 15 years. This plot was used to represent the conditions found in eastern Nebraska, where there is an average annual rainfall of about 30 inches and a high mean daily temperature during the summer months. Plot 2 was located at the substation at Mitchell, Nebraska. The soil was a light sandy loam and was handled as a dry land plot. Plot 3 was located also at Mitchell, but on a heavier soil, and the crop was grown under irrigation. Plots 2 and 3 were used to represent the dry land and irrigated potato sections of western Nebraska, where the annual rainfall is only about 16 inches, or half that of eastern Nebraska, and where the daily mean temperatures are lower than eastern Nebraska, and the night temperatures considerably lower. The meteorological data for these 3 plots are shown in Figures 3, 4, and 5. Neither Plot 2 nor 3 was under the true typical conditions found in most of western Nebraska, but they approximated it as closely as was practical.

Rainfall.—There was considerable difference in the precipitation records between eastern Nebraska and western Nebraska. During the months that the experiment was conducted, we find the following monthly precipitation records.

	April	May	June	July	Aug.	Sept.
Lincoln	2.27 in.	3.44 in.	4.95 in.	6.00 in.	3.35 in.	3.63 in.
Mitchell	0.44 in.	2.32 in.	1.84 in.	2.40 in.	1.79 in.	1.38 in.

During the time the experiment was conducted at Lincoln, that is,

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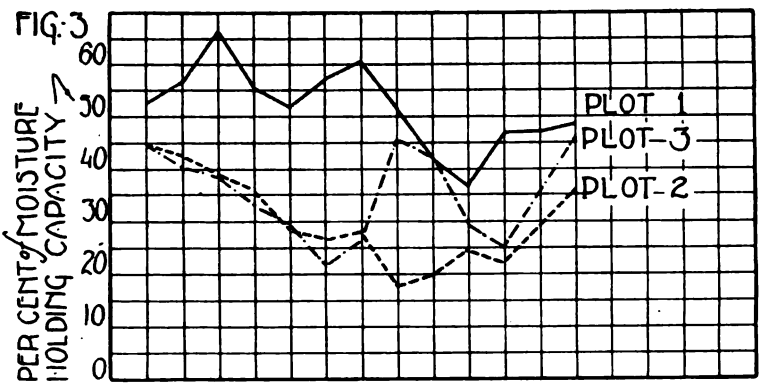

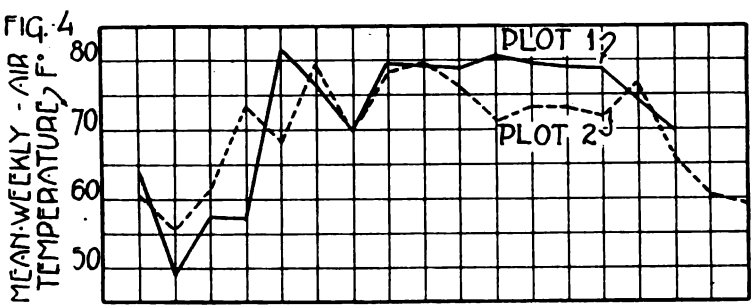

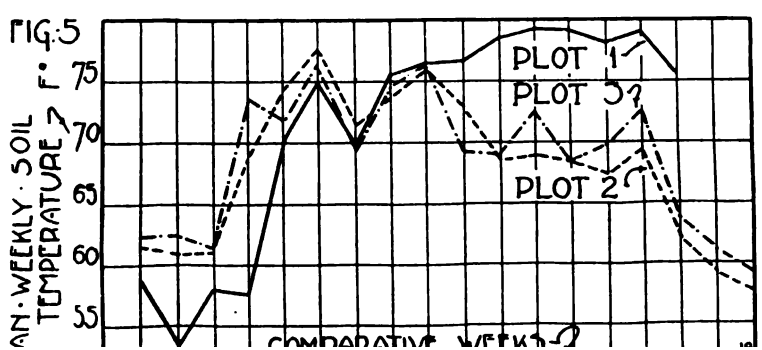

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During the experiment at Mitchell, May 20 to September 20, a period about 2 weeks longer than the Lincoln Experiment, there were 21 days with more than 0.1 inch precipitation. There were 6 periods of more than 5 days without precipitation, one being for 15 days and two for 11. During this period there were no rainfalls of 1 inch or more.

Soil moisture.—The soil moisture of the various plots is represented graphically in Figure 3. The soil samples were obtained with a soil auger for 1 ft. depths. The moisture holding capacity of the various plots, obtained by the 25 cm. cup method, was as follows: Plot 1, 50 per cent dry weight; Plot 2, 30 per cent dry weight; Plot 3, 35 per cent dry weight. The graphs in Figure 3 are based upon the percentage of the moisture holding capacity rather than upon the actual percentage of the moisture by dry weight.

It is clearly seen that Plot 1 had a higher percentage of moisture throughout the experiment. There was a considerable drop in moisture about 3 weeks before the close of the experiment. Plots 2 and 3 had about the same relative amounts of moisture for the first month of the experiment, after which Plot 3 shows an increase in moisture due to irrigation. Two applications of water were made to Plot 3, the first on July 20, the second on August 12. The results of these irrigations are clearly shown in the graphs.

Air temperature.—In Figure 4 are presented the weekly mean air temperatures for comparative weeks of the experiment for all 3 plots. During the first 4 weeks of the experiment the air temperatures were considerably lower in Plot 1 than in the others; the opposite was true during the latter part of the experiment. The air temperatures of Plots 2 and 3 were about the same since these were located within a short distance of each other; accordingly, only Plot 2 is represented in Figure 4.

Soil temperature.—The weekly mean soil temperatures for comparative weeks of the experiment for all 3 plots are plotted in Figure 5. The same thing is found here as in the comparative air temperatures except that the differences are more distinct; Plot 1 had much lower temperatures during the first half of the experiment and much higher during the latter half. Plots 2 and 3 had very similar soil temperatures.

All seed potatoes used in these plots were of the Bliss Triumph variety grown in the dry land section of western Nebraska, and were very free of all diseases, having been selected from field inspections the previous year. All seed-pieces were cut to approximately the same size. The seed was all treated with mercuric chloride. Stock cultures of *Fusarium oxysporum* No. 8, 35, and 56 were used for all inoculations. Spore suspensions for inoculating purposes were made from 14-day-old cultures on rice and hard potato agar.[1] Three different methods of inoculations were used. In Method No. 1, the seed tubers were inoculated by boring a hole in the tuber 1 to 1.5 cm. deep and 3 mm. in diameter within 1 inch of a sprout. Small glass tubes of 3 mm. bore and with one end closed were

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inoculating as in 2. All inoculations in Plot 1 were made at the same time and with the same spore suspensions. The same was true of all inoculations in Plots 2 and 3. Plot 1 was planted April 20 and dug August 3 to 8. Plots 2 and 3 were planted May 20 and dug September 21. The difference in date of planting was naturally due to the different seasons in the 2 localities.

Plot 1.—Lincoln, Nebraska. This plot contained 9 inoculated rows and 6 control rows, each row having 35 plants. The 9 inoculated rows consisted of 1 row each, for each of the 3 methods of inoculation and each of the 3 strains of *Fusarium oxysporum* used. This plot was examined several times a week thruout the period of the experiment and notes were made when any charactristic differences appeared in the plants. Only 2 plants wilted out of the 315 grown from inoculated seed-pieces. One of these plants was with Inoculation Method 2, Strain No. 56, and the other with Inoculation Method 3, Strain No. 56. All the control plants remained healthy. There was considerable yellowing of the lower leaves and tipburn of all the plants including controls due to the high temperatures.

In this plot the characteristic growth thruout the season was considerably different from that found in Plots 2 and 3. All the plants were slightly dwarfed, the leaves small, wrinkled, or curled, sometimes with a slight mottling, the appearance being very similar to the usual mosaic symptoms but in this case being due entirely to environmental conditions.

The results at digging time are shown in Tables 13 to 18 and are compared with the results found in Plots 2 and 3. Each plant was examined separately, the stems being examined for rotting and for vascular discoloration and the new tubers for vascular discoloration. Many of the plants were mature and the stems had dried out too much to observe infection accurately; these are listed in the tables as "dead."

Plot 2.—Dry land plot at Mitchell, Nebraska. The seed was inoculated and planted in the same way as in Plot 1, except that 33 hills were planted with each of the 3 strains and each of the 3 methods of inoculation. The distance of these plots from the

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TABLE 13.—*Percentage of plants wilted*

Strain of *Fusarium oxysporum*	Method of inoculation	Plot 1	Plot 2	Plot 3
		Per cent	*Per cent*	*Per cent*
	1	0	3.0	10.0
8	2	0	78.5	14.2
	3	0	69.6	10.0
	1	0	0	3.1
35	2	0	69.6	3.3
	3	0	13.7	3.1
	1	0	9.0	6.8
56	2	2.8	3.5	0
	3	2.8	7.1	14.2
	Control.....	0	0	0

Plot 3.—Planted in the same way and at the same time as Plot 2. This plot was irrigated twice. The plants were very vigorous thruout the experiment.

Results.—The percentage of germination was higher in Plot 1 than in Plot 2, and Plot 3 showed the lowest percentage of germination. However, as the controls showed a lower percentage than the inoculated rows in Plots 2 and 3, no conclusions can be drawn as to the effects of inoculations upon germination. Therefore, in the following tables and discussion, the actual number of plants is used as the basis for calculating percentages, rather than the number of seed-pieces planted.

Considering the actual wilting of the plant, i. e., wilting

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Comparing now the resulting tubers from the plants in Plots 2 and 3 where wilting occurred, by examining all tubers at digging time and classing as infected all tubers showing distinct vascular discoloration or stem-end rotting, we find in weight comparisons, which were found to be more accurate than the number of infected tubers, the percentages presented in Table 14.

TABLE 14.—*Comparative percentages of infected tubers by weight, from wilted plants and healthy plants of inoculated rows and healthy plants from control rows*

		Inoculated rows		Control rows
		Wilted plants	Healthy plants	Healthy plants
Plot 2	No. of plants	79	166	138
	Percentage of infected tubers by weight	85.9	33.7	5.3
Plot 3	No. of plants	19	220	144
	Percentage of infected tubers by weight	24.4	15.5	0.4

Thus, the number of tubers having either vascular discoloration or rotting can be correlated not only with wilt but also with apparently healthy plants grown from inoculated seed. The amount of infection was also much greater in Plot 2 than in Plot 3.

If we now compare the total yield from the rows having wilted plants in Plots 2 and 3 (as shown in Table 13), we find

TABLE 15.—*Comparative yields in grams per plant of control rows and wilted and healthy plants in inoculated rows*

		Plot 2	Plot 3
		Grams	*Grams*
	Wilted plants	134	500

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that the total yield per plant can be correlated, not only with wilted plants, but also with healthy plants from inoculated seed. These results are tabulated in Table 15. The higher yields in Plot 3 where the percentage of infection was low was particularly noticeable. However, the cultural conditions must be taken into consideration in comparing yields in different plots, and of course Plot 3 would have a much higher yield, due to irrigation. The comparison between the different lots of plants within Plot 3 is, however, nearly as marked as in Plot 2.

If we now use for a comparison the number of stems either dead or showing vascular discoloration, we find the following percentages:

		Plot 2	Plot 3
Inoculated rows...	Wilted plants	93 per cent	94 per cent
	Healthy plants	88 per cent	83 per cent
Control rows.....	Healthy plants	32 per cent	13 per cent

The same relation holds here as in the table, where the infected tubers were used as a basis of comparison. The percentages, however, were all higher and the difference between inoculated and controls was not as great. This was chiefly due to the fact that many of the stems necessarily listed as dead had matured normally; also the differences between the plants in Plots 2 and 3 are chiefly due to the fact that the plants remained green longer under the irrigated conditions. This index, therefore, is not a very reliable one in judging the amount of disease.

Disregarding wilting as the chief symptom of the disease and comparing the several experimental plots simply on the basis of inoculated seed-pieces as compared with control rows, we find several interesting comparisons.

Table 16 shows the percentage by weight of total tubers showing vascular discoloration or rotting in the various plots.

This table shows that by far the greatest amount of infection took place in Plot 2. The next largest was in Plot 3, except in case of Inoculation Method 2 with *Fusarium oxysporum* No. 56, which was greatest in Plot 1. However, the total of all three types of inoculation with Strain No. 56 was greatest in Plot 2. The amount of infection in Plot 1 was very small, except with Inoculation Method 2, the other inoculations often running lower than the controls, which average well in Plots 1 and 2 and were much lower in Plot 3.

It is also seen that with reference to the strain of *Fusarium oxysporum* used more infected tubers resulted with inoculations

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TABLE 16.—*Percentage by weight of resulting tubers having vascular discoloration or stem end rot*

Strain of *Fusarium oxysporum*	Method of inoculation	Plot 1	Plot 2	Plot 3
		Per cent	*Per cent*	*Per cent*
	1	1.2	16.1	0.3
8	2	18.2	85.1	35.7
	3	0.0	88.1	63.4
	1	0.6	11.9	1.3
35	2	10.8	77.6	32.7
	3	2.7	62.7	12.2
	1	2.3	11.8	3.7
56	2	34.0	25.9	3.7
	3	12.0	29.6	4.0
	Control.....	5.0	5.1	0.4

with Strain No. 8 except in Plot 1, where the amount of infection was small and the probable error would be correspondingly greater,—this in spite of the fact that Strain 8 is the oldest strain of the three. As regards the method of inoculation, there was uniformly more infection obtained with Inoculation Methods 2 and 3 than with 1. There does not appear from these results to be a great advantage in allowing the cut surfaces of the seed-piece to callous over before planting.

If, instead of comparing the amount of infection by the total weight of tubers, we compare the number of plants having infected tubers, the following results are found in Table 17.

This table shows the same comparative results as those found

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TABLE 17.—*Percentage of mature plants having infected tubers*

Strain of *Fusarium oxysporum*	Method of inoculation	Plot 1	Plot 2	Plot 3
		Per cent	*Per cent*	*Per cent*
	1	2.7	12.1	3.7
8	2	20.0	92.0	57.1
	3	0.0	87.8	86.6
	1	2.7	27.2	3.1
35	2	5.5	85.5	70.0
	3	13.8	79.3	32.2
	1	11.1	24.2	6.8
56	2	34.2	46.4	18.5
	3	30.5	39.2	14.3
	Control.....	10.9	8.8	1.3

Averaging the total number of infected tubers in all 3 methods of inoculations, we find that in Plot 1 the greatest infection, 30 per cent, was with Strain No. 56; in Plot 2, 67.4 per cent, with Strain No. 35; and Plot 3, 50.5 per cent, with Strain No. 8.

The effect of these inoculations on the actual yield of tubers is shown in Table 18, the results being given in weight per plant rather than in total weight for the row, because many plants did not germinate and yet this failure to germinate could not be correlated with the disease.

This shows a higher yield from control plants than from any

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TABLE 18.—*Average weight of tubers in grams per plant*

Strain of *Fusarium oxysporum*	Method of inoculation	Plot 1	Plot 2	Plot 3
		Grams	*Grams*	*Grams*
	1	99	86	723
8	2	170	121	658
	3	200	166	383
	1	175	316	751
35	2	161	169	743
	3	186	233	1,133
	1	185	302	599
56	2	94	318	868
	3	168	296	582
Average of	inoculations....	159	234	715
	Controls.....	241	369	973

sentative lot of 83 tubers was, however, selected from the various plots, and isolations were made from these, usually 3 isolations being made from each tuber. *Fusarium oxysporum* was recovered from 11 tubers, Fusarium spp. exclusive of *F. oxysporum* from 17 tubers, miscellaneous fungi from 3, and 52 tubers failed to yield any organism in culture. From 36 tubers having varying degrees of vascular discoloration in the absence of stem end rot, *F. oxysporum* was isolated only twice, Fusarium spp. twice, and 128 cultures from the remaining 32 tubers were sterile. From 42 tubers showing both stem-end rot and vascular discoloration, *F. oxysporum* was isolated from 9 of them, Fusarium spp. from 12, miscellaneous fungi from 3, and cultures from 18 tubers remained sterile. Five tubers of this lot showing stem-end rot but no vascular discoloration yielded in culture Fusarium spp. from 3, and bacterial and miscellaneous fungi from 2. While the number of tubers examined was comparatively small, the results were well in accordance with hundreds of other isolations made at various times by the writer.

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DISCUSSION

The infection of the plants through the seed-piece from the soil was shown by MacMillan (1919) to be the chief method of infection under irrigated conditions of Colorado. Such infection in the fields in Michigan is not common in the author's experience. It would be assumed that such a type of infection would be more prevalent in the presence of high soil moistures. The results of the field experiments recorded here do not, however, prove this contention to be true. Judging the amount of infection either by the number of wilted plants, the vascular discoloration of the stem, of the tuber, or by comparative yields, it was found that under the 3 widely different environmental conditions present in these experiments the best development of the disease was in the dry land plots of western Nebraska. Comparing this plot (No. 2) with the other plots as to environmental conditions, we find that the soil moisture was less during the entire experiment than that in Plot 1, where the smallest amount of disease developed, and that there was also a much smaller amount of soil moisture than in the irrigated plot (No. 3) during the latter half of the experiment. The corresponding temperatures both of soil and of air were relatively higher than in Plot 1 during the earlier part of the experiment and lower during the later part.

Just what interpretation can be placed on these results is not entirely clear, as the evidence presented here is only for one year. It is evident in these experiments as in all the others reported in this paper that the amount of infection secured by artificial inoculations with pure cultures is so small that it is difficult to make a definite and clear-cut interpretation of the results. No effect was observed on the germinating power of the seed due to inoculation.

RELATION OF ENVIRONMENT TO THE DISEASE

Fusarium oxysporum is capable of living in the soil saprophytically or of overwintering in the seed tuber under a variety of conditions. It is only capable of producing severe effects on its host plant when conditions are very favorable for the infection and progress of the disease. These conditions made up of the complex relations of many factors may determine not only

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References in the literature on the relation of climatic factors to the disease, while abounding in incomplete observational data, are rather meagre in exact meteorological records in relation to the various manifestations of the disease. Information regarding soil temperatures and moistures is regrettably lacking. Nevertheless many conclusions are set forth as to the effect of different factors upon the disease. Many of these are misleading owing to the incompleteness of the data and to the casual consideration of the disease *in toto*, rather than to a close comparison of the successive stages in its development in relation to the environmental factors.

Fusarium wilt has always been considered to be a disease favored by warm climates, and some authors have held that a combination of high temperature and drought is particularly favorable for its development. While it is true that the disease is not reported as being serious in some of the northern potato producing states, yet considerable infection was found by the writer in the upper peninsula of Michigan in 1914 and 1915. In Nebraska the disease is much more prevalent in the western section of the State with an altitude about 3,500 feet higher and a correspondingly cooler temperature, than in the eastern part of the State. Furthermore, we find that such generalizations do not hold when we examine individual fields, experimental plots, or sometimes even potato growing sections of considerable size.

Manns (1911) observed that drought apparently hastened the yellowing symptoms of the disease, but he was unable to decide its influence upon the activity of the organism. He states (p. 317) that in the history of the disease at the Ohio station—

> the severest attack occurred during the most favorable season we have had in a long time, viz., in 1909. The temperature and rainfall that season were very equitable.

He believed (p. 317) that as far as reducing the yields was concerned the disease would cause—

> as great a percent in reduction under favorable conditions as under drouth.

He claimed, however, that the disease would penetrate much deeper into the tubers under conditions of drought.

MacMillan (1919) stated (p. 209):

> Temperatures of the soil are vital as regards infection. The critical temperature for infection has not been determined and it varies for the manner of infection. Seed-piece infection will occur at a considerable lower temperature than root infection.

Bisby (1920), observing the prevalence of "foot-rot" in rela-

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tion to climatic factors, finds that "foot-rot" develops only when abundant moisture is present, even tho the temperature may be considerably below normal, and that it occurs only late in the season, irrespective of whether the conditions have been favorable from planting time on.

Haskell (1919) finds that soil temperature is the chief factor in influencing the disease, and states (p. 258) that—

the disease is most severe in places where high summer temperatures prevail at the time when tuber formation is in progress * * * Within Dutchess County there is a distinct correlation between the amount of disease and factors influencing soil temperature such as altitude, exposure of fields and shading of plants.

He had difficulty in obtaining infection with artificial inoculations unless a high soil temperature, 36° to 40°C., was used.

Edson and Shapovalov (1920) report an experiment in which seed tubers inoculated with *Fusarium oxysporum* were planted at two different dates. The experiment was conducted in the vicinity of Washington, D. C. They conclude that—

there were more tubers infected with *Fusarium oxysporum* in the early crop grown at higher temperature, than in the late crop grown at lower temperature.

They give no detailed information regarding temperature and moisture conditions during the experiment.

Experiments made by the author and discussed elsewhere in this paper show results very similar to those reported by Manns (1911). For instance, in working with infected seed tubers, the disease was reproduced abundantly in Michigan in 1915, a season with low temperatures and high precipitations; while in 1916 similar experiments yielded negative results when the temperatures were extremely high and precipitations very low, in fact, one of the hottest and driest seasons on record for Michigan. Inoculation experiments also gave negative results during this season.

Experiments with inoculated seed in Nebraska have shown that the disease is favored by the environmental conditions found in the dry land sections of western Nebraska more than in either the irrigated fields having a higher soil moisture or the fields of eastern Nebraska with both higher temperature and moisture during the entire season. In the experiments under control con-

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In the temperature experiments, plants infected at high temperatures and changed to lower temperatures recovered and showed no wilt symptoms even tho the organism was present in the host tissue. Plants started at low temperatures and later changed to higher temperatures showed as much disease as those grown at a maintained high temperature.

Soil moisture may act in a variety of ways, determining the distribution of the organism thru the soil, and by its effect on the host plant determining the entrance of the organism. Later changes in moisture not only would have a profound effect upon the type of injury, i. e., rotting of the stem or roots, but would also affect the symptoms of the disease by bringing about conditions enabling the host plant either to counteract the detrimental effects of the organism or to accelerate the action of the parasite and weaken the host.

Temperature would affect not only the growth of the organism but also the growth of the host and determine the ability of the organism to enter the host. The conditions favorable for this infection may not be favorable for the further progress of the disease within the host plant and the susceptibility of the host to succumb to the attack of the parasite.

Because of these complex reactions we often find conditions during a greater part of the season that would be favorable for the progress of the disease, but unless the conditions had been favorable for the inital infection, these later environmental conditions would have no effect. Conditions of drought, while favoring the later stages of the disease, are apparently not favorable for infection. Drought combined with high temperatures may cause a browning of the vascular system in the absence of the parasite, a condition often mistaken for Fusarium wilt.

Thus it is clear that observational data on environmental conditions to be of value must take into consideration all conditions influencing the disease from the time of planting until maturity. It is only by the accumulation of data from all potato growing sections, combined with a careful examination of the plants as regards the method of infection and resulting symptoms, that we can come to a clear understanding of the action of this disease.

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COLLEGE OF AGRICULTURE UNIVERSITY OF NEBRASKA
AGRICULTURAL EXPERIMENT STATION
RESEARCH BULLETIN 24

SEED POTATO INVESTIGATIONS

H. O. WERNER AND R. F. HOWARD
Department of Horticulture

LINCOLN, NEBRASKA
DECEMBER, 1923

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SUMMARY

1. The soil and climatic conditions in the high altitude region of western Nebraska are suitable for the production and perpetuation of high-yielding seed potatoes.

2. Tuber line studies, with numerous lots of different varieties, revealed early and late maturing strains as well as a type of degeneracy very similar to, or identical with, "spindling tuber" (recently described by Shultz and Folsom).

3. This degeneracy manifests itself by a stiff, upright habit of growth and by an elongation of the tubers. Strains affected by it never recover, but become progressively weaker.

4. The degeneracy most common in western Nebraska is perpetuated thru the tubers and appears to be transmitted from plant to plant in the field.

5. Irrigation produces conditions more conducive to the rapid increase of this degeneracy than dry land culture, the per cent of degeneracy increasing and the yield decreasing with each additional year of irrigation.

6. This type of degeneracy has been studied in 10 different varieties.

7. Many lots from isolated fields in the newer dry land potato growing sections are relatively free from this degeneracy.

8. This type of degeneracy causes very serious decrease in tuber yields till eventually no marketable tubers are produced.

9. Seed stocks produced on dry land at the highest altitude proved to be superior in point of quality and yield of tubers produced, when

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SEED POTATO INVESTIGATIONS*

H. O. WERNER AND R. F. HOWARD

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INTRODUCTION

The Irish potato is one of the important cultivated crops in Nebraska. The average annual production for the 10-year period 1913-22 was 9,179,000 bushels. Approximately 75 per cent of the car lot shipments originate in 7 of the western counties. The other commercial shipping regions, which normally harvest and market their crops somewhat earlier than the western counties, are the Platte and Republican River Valleys in the south central and Brown County in the north central part of the State. The potato is also grown as an early truck crop near the cities of eastern Nebraska. The total garden production thruout the State is approximately equal to the car lot shipments.

The climatic and soil conditions of western Nebraska are especially suitable for the production of late potatoes. The altitude of this section is over 3,500 feet, thus making a short growing season, with a mean temperature of 66° to 68° F. (figs. 1 and 2). In these respects the conditions in western Nebraska are similar to those in the potato growing regions of Wisconsin, Minnesota, Michigan, and North Dakota (Reed, 1918). The annual rainfall in western Nebraska is 15 to 18 inches (fig. 3), while the potato regions of the Northern States have a precipitation of 20 to 30 inches (Kincer, 1922). This same relative difference exists when only summer rainfall is considered. Relative humidity is also lower in western Nebraska.

The relation between satisfactory yields and good seed has long been recognized by potato growers. It is common

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recently this belief has been a common one in western Nebraska, even tho certain climatic conditions there are very similar to those of the northern seed-producing states. Many western Nebraska growers have demonstrated, however, that satisfactory yields may be maintained indefinitely by the use of local seed, especially that produced on dry land.

Attempts have been made to determine why yields decrease when the potato crop is grown under certain unfavorable climatic conditions. Emerson (1914) compared northern seed with local seed at Lincoln. He noted a 23 per cent reduction in yield the second year as a result of culture for a

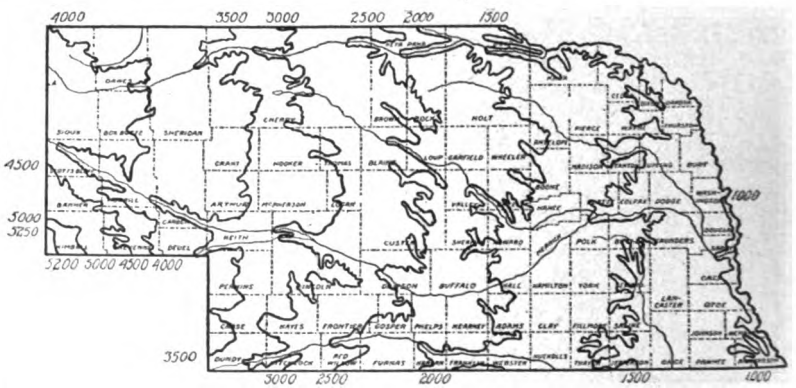

FIG. 1.—Altitude variation (in feet) in Nebraska (after Warren). The altitude ranges from less than 1,000 feet in the southeastern part of the State to more than 5,250 feet in the western part (Kimball County). The seed potato industry has been most extensively developed in the areas above 3,500 feet. Altitude of trial plats given in Table 1.

single season in eastern Nebraska. This reduction in yield was 32 per cent after 2 years and 46 per cent after 8 years of continuous culture at Lincoln. In connection with this work he grew certain plats under a heavy straw mulch. The tubers produced under a mulch gave yields the following year almost identical with those from fresh northern stock. Yields did not decrease with continuous mulching. He found, further, that potatoes which had deteriorated as a result of cultivation could be rejuvenated to their original productiveness by growing them under a mulch for a single season. It has since been found (Werner, 1922) that the soil temperature (at a depth of 4 inches) is lower in the mulched plat.

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The mean difference for the period April 15th to August 28th was 7° F. This difference was from 4° to 6° greater during July and August.

In the Atlantic Coast and Southern States, the production of a late or fall crop of potatoes for use as seed stock the following spring is quite a common practice. Such potatoes have been found to be almost equal to northern seed. (Rosa, 1922; Cooper, 1922.) Such a fall or second crop is developed under relatively low temperatures. This further suggests that temperature is an important contributing factor in determining the relative vigor of seed potatoes.

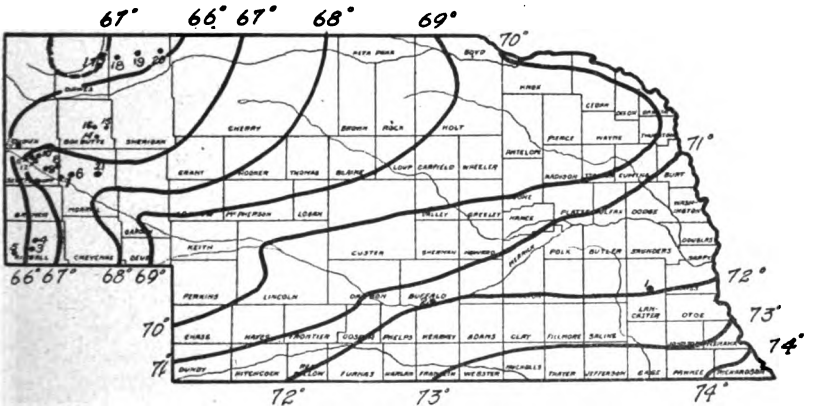

FIG. 2.—Normal isotherm map of Nebraska, for the late potato crop season (June 1 to September 30), based on temperature records taken at U. S. Weather Bureau observation stations for period of 10 years or more. Numbers with dots refer to name, etc., of trial plats given in Table 1. Commercial seed potato production has not developed south or east of the 68° isotherm.

In the light of the temperature relations referred to above, it seemed reasonable to suppose that good seed could be produced in the high altitude regions of western Nebraska. Preliminary trials were made with western Nebraska stock at Lincoln (1915 and 1916) and various points in Southern States (1916) with a view of determining the seed value of this stock. Most of these lots gave very satisfactory yields when compared with seed from various northern seed-producing states. Later and more comprehensive tests of a similar nature revealed a large number of high-yielding western Nebraska lots. (Edgerton and Tiebout, 1921; Tiebout, 1921; Stuart, 1920; Rosa, 1922).

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TABLE 1—*Location and description of experimental trial plats*

Plat No.	Nearest town	County	Kind of culture	Soil type	Altitude	Potato growing season June 1—September 30		Name of cooperating farmer
						Normal mean daily temperature	Normal mean total rainfall	
(1)	(2)	(3)	(4)	(5)	*Feet* (6)	°*F.* (7)	*Inches* (8)	(9)
1	Lincoln	Lancaster	Dry	Silt loam	1,200	72.5	14.4	Exp. Station Farm
2	Kearney	Buffalo	Irrigation	Silt loam	2,150	71.9	13.7	Several farms
3	Kimball	Kimball	Dry	Sidney fine sandy loam	4,750	66.7	7.37	Art Bickle
4	Kimball	Kimball	Irrigation	Tripp very fine sandy loam	4,670	66.7	7.37	J. Pedrett
5	Bushnell	Kimball	Dry	Sidney loam	5,200	66.7	7.37	Aug. Gadeken
6	Bayard	Morrill	Irrigation	Bridgeport very fine sandy loam	3,820	67.8	7.38	Seth and Earnest Bankson
7	Bayard	Morrill	Irrigation	Tripp very fine sandy loam	3,850	67.8	7.38	G. W. Suhr
8	Minatare	Scotts Bluff	Irrigation	Valentine very fine sand	4,050	67.9	7.36	R. O. Fithian
9	Minatare	Scotts Bluff	Irrigation	Tripp very fine sandy loam	3,965	67.9	7.36	C. C. Parrish
10	Scottsbluff	Scotts Bluff	Irrigation	Valentine very fine sand	4,120	67.9	7.36	L. A. Montz
11	Mitchell	Scotts Bluff	Irrigation	Tripp very fine sandy loam	4,080	66.8	7.9	Scotts Bluff Exp. Farm
12	Mitchell	Scotts Bluff	Dry			66.8	7.9	
13	Morrill	Sioux	Irrigation	Bridgeport very fine sandy loam	4,100	66.8	7.9	Peter Janssen
14	Alliance	Box Butte	Dry	Rosebud very fine sandy loam	4,000	About same as Mitchell	About 7.5	Wayne Wilson
15	Alliance	Box Butte	Dry	Valentine silt loam				E. A. Bennett
16	Alliance	Box Butte	Dry	Rosebud silt loam				Wm. Newman
17	Chadron	Dawes	Dry	Tripp very fine sandy loam	3,400	About 67.8	About 8.8	J. C. Justeson
18	Hay Springs	Sheridan	Dry	Rosebud very fine sandy loam	3,821	65.9	8.72	
19	Rushville	Sheridan	Dry	Dawes very fine sandy loam	3,700	(Similar to Hay Springs)		Ira Barker
20	Gordon	Sheridan	Dry	Tripp very fine sandy loam	3,550	66.0	7.94	Geo. Stannard
21	Angora	Morrill	Dry	Valentine very fine sandy loam	4,000	67.8	7.38	W. W. Thompson

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The mosaic disease is known to be one of the most important factors affecting potato production in the South. These trials showed that mosaic was less prevalent in seed from Nebraska than in that from the more humid regions in the states farther east and north.* (Edgerton and Tiebout, 1921; Tiebout, 1921.)

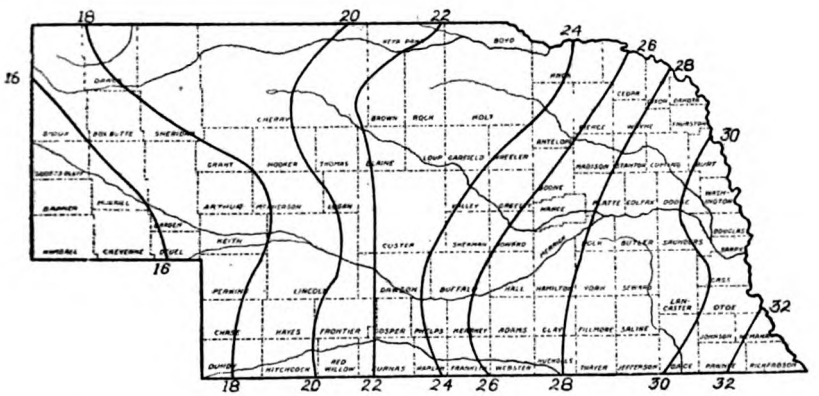

FIG. 3.—Average annual precipitation for different sections of Nebraska (inches). Based on U. S. Weather Bureau records. (From Nebr. Research Bul. 19.) Data for various trial plats in Table 1.

In the tests made at Lincoln in 1915-1916 with seed from western Nebraska there was considerable variation in yield. These differences in yield together with the uncertainty as to the necessity of importing northern seed into western Nebraska justified further investigation.

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* Mosaic readings made April 23-24, 1923, at Baton Rouge, La., by Werner, on 81 distinct lots of western Nebraska Triumph seed showed distinct mosaic symptoms on 4.8 per cent of the plants. In the same trials Wisconsin seed (4 lots) averaged 10.1 per cent, North Dakota (5 lots) 17.1 per cent, Montana (8 lots) 3.0 per cent, and three check lots picked up on local markets 56.9 per cent. In these same trials, 26 Nebraska lots contained from 0 to 1.0 per cent mosaic. Similar readings were made and reported by Tiebout and Edgerton, 1921. (Trials conducted by Louisiana State Experiment Station, and U. S. D. A.–B. P. I.)

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OBJECTS OF INVESTIGATIONS

The objects of the investigations reported in this bulletin were:

To determine the condition of western Nebraska seed stock by the tuber unit method and by comparative trials in western Nebraska and various other points.

To determine the effect of culture, place, disease, etc., upon seed value.

To perfect methods of applying results to seed production in western Nebraska.

EXPERIMENTS AND RESULTS

LOCATION OF PLATS AND DISEASE CONTROL PRECAUTIONS

All of the experimental plats were located in the western part of the State except two—one at Kearney and one at Lincoln. The soil type, altitude, moisture and temperature conditions, and the name of the cooperating grower, together with plat number, are shown in Table 1. The plats are referred to by town and number in the tables and discussion. The experimental plantings were usually made in a commercial field.

The usual methods of disease control were employed. The plantings were always made on land that had not been in potatoes for the 3 or 4 previous years. The seed was disinfected with corrosive sublimate except in a few instances where the tubers had sprouted excessively. Blackleg was almost entirely absent. Fusarium was never present to any great extent in any of the plats. A relatively small per cent of mosaic has been found to exist in western Nebraska. This is comprehensively shown by the fact that the 81 different lots, when grown in Louisiana, under optimum conditions for making mosaic symptoms visible, showed only 4.8 per cent of this disease. Whenever plants affected with mosaic were discovered they were removed from the plats.

TUBER UNIT TRIALS

TRIALS IN 1917

Preliminary tests made before 1917 showed a wide variation in the productivity of various lots of western Nebraska seed potatoes. It was apparent in most cases that a given lot contained both productive and unproductive plants. In order to study the nature of these variations, tuber unit trials were begun in 1917. The early tuber unit trials consisted in selecting a large number of uniform tubers of different varieties from cellars of commercial growers and plant-

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ing them in such a way that their progeny could be studied separately. Each tuber was cut lengthwise into 4 equal parts and these seed pieces planted in adjacent spaces in the row. The space between the 4 hill units was the same as that between hills. Each tuber unit was numbered and labeled by means of a wire stake and metal tag.

One thousand Triumph tubers were selected from some Scotts Bluff County irrigated stock and planted by the tuber

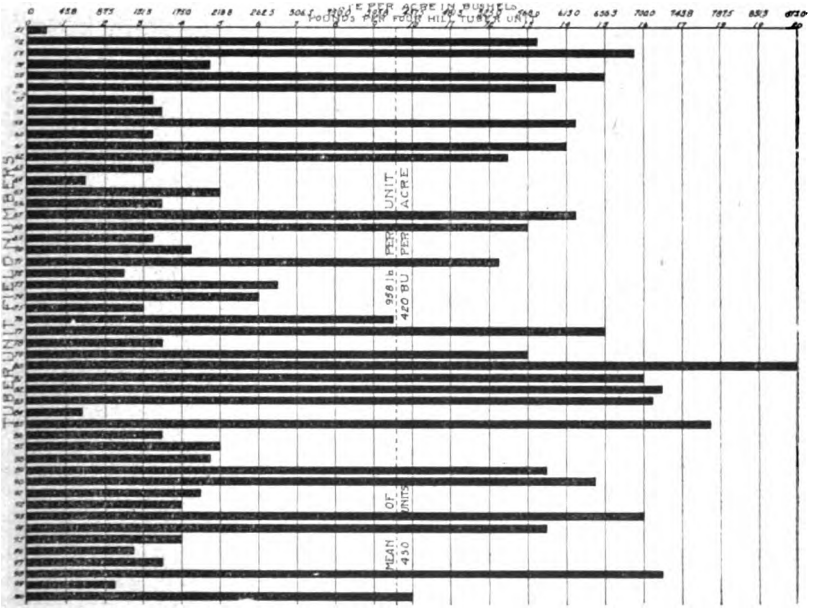

FIG. 4.—Total yield produced by 50 consecutive tuber units of Triumph potatoes in Scotts Bluff County, 1917, (Plat 9). (For curve of 450 units see fig. 5.) These are fairly representative of any other 50 unit group in this strain. The very good and very poor units were scattered thruout the field.

unit method under irrigation (Plat 9). Striking uniformity of the 4 plants within a unit and a remarkable difference in vigor between units were plainly evident as the season progressed. Within a unit the 4 plants were similar not only in general appearance but also in habit of growth, size, and date of maturity. At harvest time it was found that the hills within a unit were also uniform with regard to tuber type and yield.

The differences between the units are illustrated by a

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variation in yield from 0 to 20 pounds. In figure 4 the yields of 50 consecutive units are graphically shown. This graph is representative of the other 950 units. The high and low yielding units were found thruout the field in such manner as to show that they were the result of conditions within the seed tubers rather than of varying soil conditions. The end hill of a good unit adjacent to a poor one was favored to some extent on account of better growing conditions. However, reasoning from the work of Stewart (1915), the uncorrected error per 4-hill unit in such

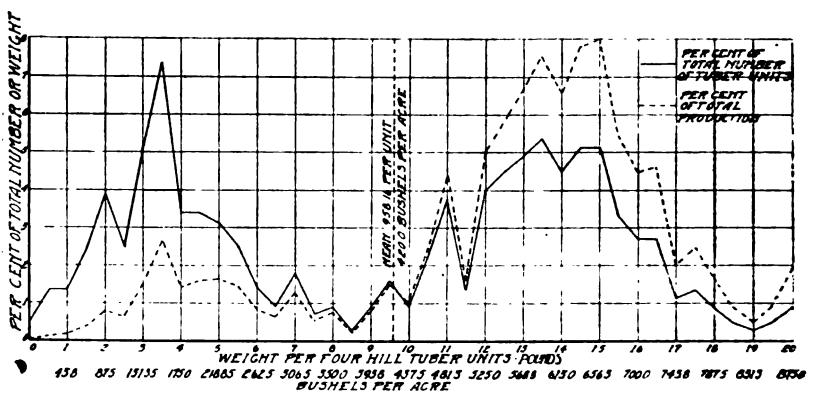
PER CENT OF TOTAL NUMBER OF WEIGHT
PER CENT OF TOTAL NUMBER OF TUBER UNITS
PER CENT OF TOTAL PRODUCTION
PER CENT 19.4 PER UNIT
400 BUSHELS PER ACRE
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
WEIGHT PER FOUR HILL TUBER UNITS POUNDS
438 875 1313.5 1750 2187.5 2625 3062.5 3500 3938 4375 4813 5250 5688 6125 6563 7000 7438 7875 8313 8750
BUSHELS PER ACRE

FIG. 5.—Distribution of yield per unit of 450 Triumph tuber units, on basis of percentage of total number and total weight, Scotts Bluff County, 1917, irrigation, (Plat 9). A bimodal curve of this type is unusual. The left curve comprises all poor type run-out units, the right-hand curve comprises vigorous high yielding good type units. The individual unit yields (of 50 units) plotted in figure 4 show how the units of both groups were scattered thruout the field. This group of units was in a rapidly degenerating condition.

cases was probably not more than 6 to 8 per cent. The units fell into 2 distinct groups, high yielding and low yielding. Of the total number of units, 44.4 per cent produced only 18.8 per cent of the total yield. Thus 55.6 per cent of the units produced 81.2 per cent of the yield. When these facts are shown graphically for the 450 units that were harvested, they produce the bimodal curve shown in figure 5. The low yielding units were characterized by a vigor proportionate to yield and a distinctly upright habit of growth. They were further characterized by having few stems, generally not branched. The tubers from such plants were often elongated and the skin color was much lighter than normal.

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These all were in the left modal group. The right modal group contained the vigorous high yielding lots of better type.

The same year 266 Triumph units from dry land stock were planted in a similar manner at Alliance (Plat 11). On

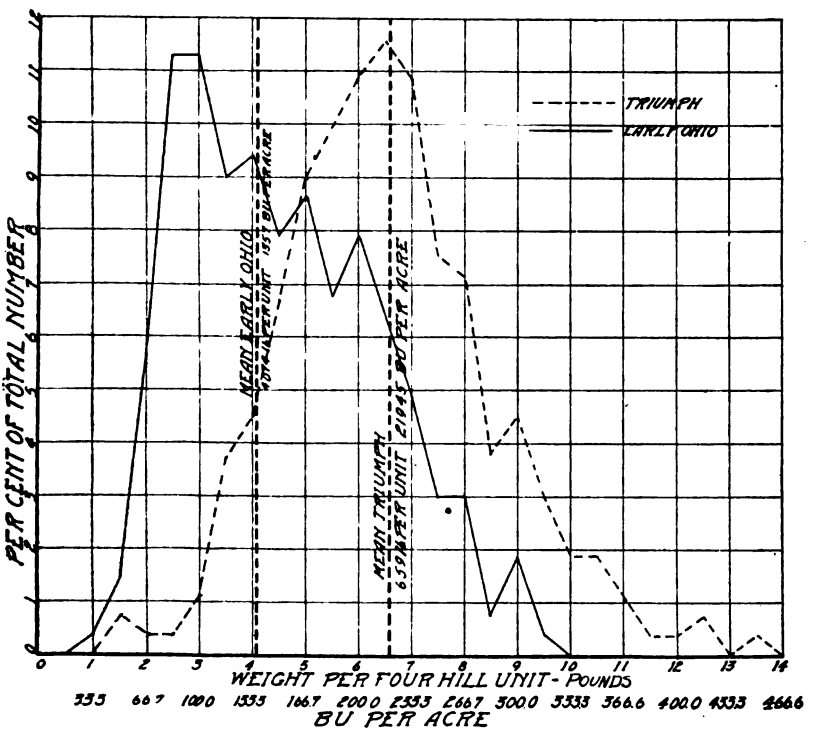
TRIUMPH
EARLY OHIO
PER CENT OF TOTAL NUMBER
WEIGHT PER FOUR HILL UNIT - POUNDS
BU PER ACRE
333 667 1000 1333 1667 2000 2333 2667 3000 3333 3666 4000 4333 4666

FIG. 6.—Distribution by yield of 266 tuber units of both Early Ohio and Triumph dry land potatoes at Alliance in 1917. Graph arranged on percentage basis. The Triumph strain produced a greater mean yield with a greater range than the Early Ohio. These curves are very similar to those in figure 8. Altho the average yield of Triumph potatoes was 219.45 bushels per acre, a high yield for dry land culture, a number of units yielded 300 bushels or more per acre.

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A like number (266) of dry land Early Ohio tubers were also planted at Alliance (Plat 14). The yields from these

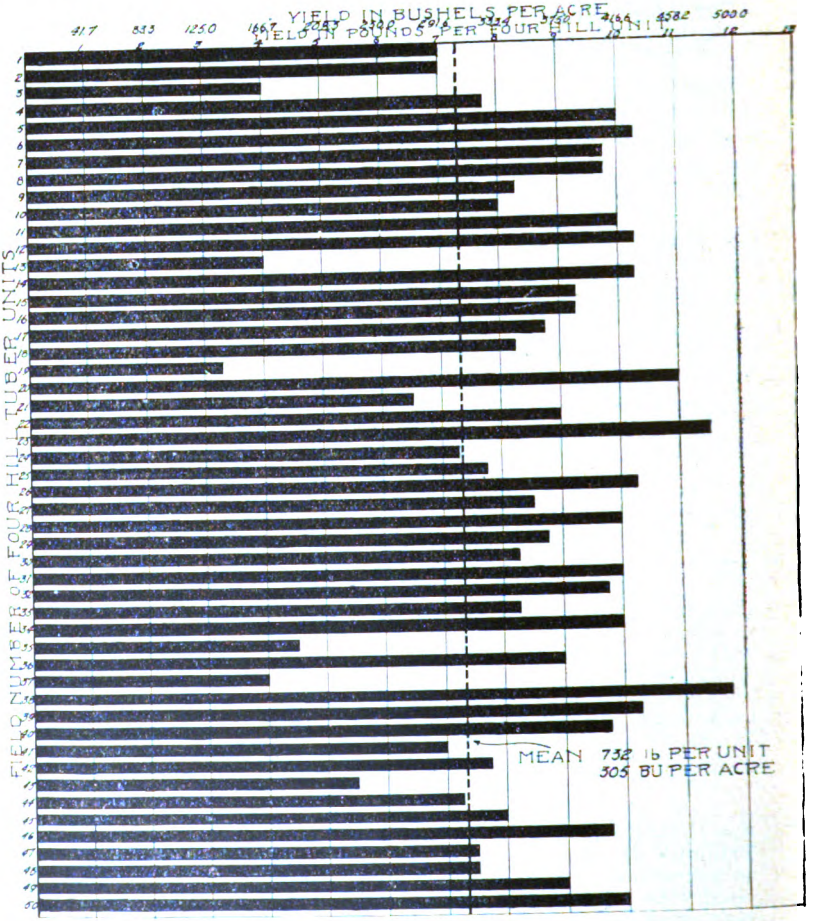

FIG. 7.—Graphic presentation of total yield data for the first 50 tuber units of Pearl potatoes, of units 1 to 250, grown at Kimball, 1917, (Plat 4) with irrigation. Variations between tuber units were mostly due to variation in the seed. Land variation was not a serious factor for frequently very low and very high yielding units were adjacent in the row. The low producing units were degenerates and generally had poor type tubers. See also figure 8 and Tables 2 and 5.

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were somewhat lower, altho in general the results were very similar to those secured with Triumphs at the same place (fig. 6).

The unit studies with the Pearl variety in Kimball County differed from the others somewhat, in that both dry land and irrigated stock were planted; under irrigation in one instance (Plat 4) and on dry land in another (Plat 3). The original stock of this variety came from Wisconsin in 1910. From this stock 500 tubers were selected from a lot that had been grown on dry land the seven years previous and an equal number from a lot which had been grown with irrigation during the same period. Half of these tubers—that is, 250 tubers of each lot—were planted on dry land and the remainder under irrigation, for the additional purpose of determining the influence of continuous irrigation and of dry land culture on the stock. Variations of both seed stocks under both sets of cultural conditions were not unlike those secured at Alliance with Triumphs and Ohios. The yields of 50 irrigated units from continuously irrigated stock are shown graphically in figure 7.

The difference in yield under irrigation between irrigated and dry land seed stock was not great. However, the range in variation as well as total yield was slightly greater in the case of the continuous dry land stock (Table 2 and fig. 8). The average yield per hill and the extremes in yield were greater in the irrigated plat than under dry land conditions. A study of this table and the related chart (fig. 8) shows that the yields of the units were distributed along a normal frequency curve with the highest number of units yielding at any one rate (mode) relatively close to the average yield of the lot (mean). In view of later work, it is believed that the reason the dry land stock did not outyield the continuously irrigated seed in this particular case (which was rather exceptional) was because the grower of the irrigated stock annually was more careful in selecting his seed for type, thus probably eliminating some undesirable strains or disease carrying tubers.

The correlation of weight and number of marketable (U. S. No. 1 grade) tubers per 4-hill unit of 250 continuously irrigated units grown under irrigation is shown in Table 3. The more vigorous units not only produced more potatoes, but also developed more large tubers.

The low-yielding Pearl units were also characterized by weak, spindling tops and the tubers from such plants were

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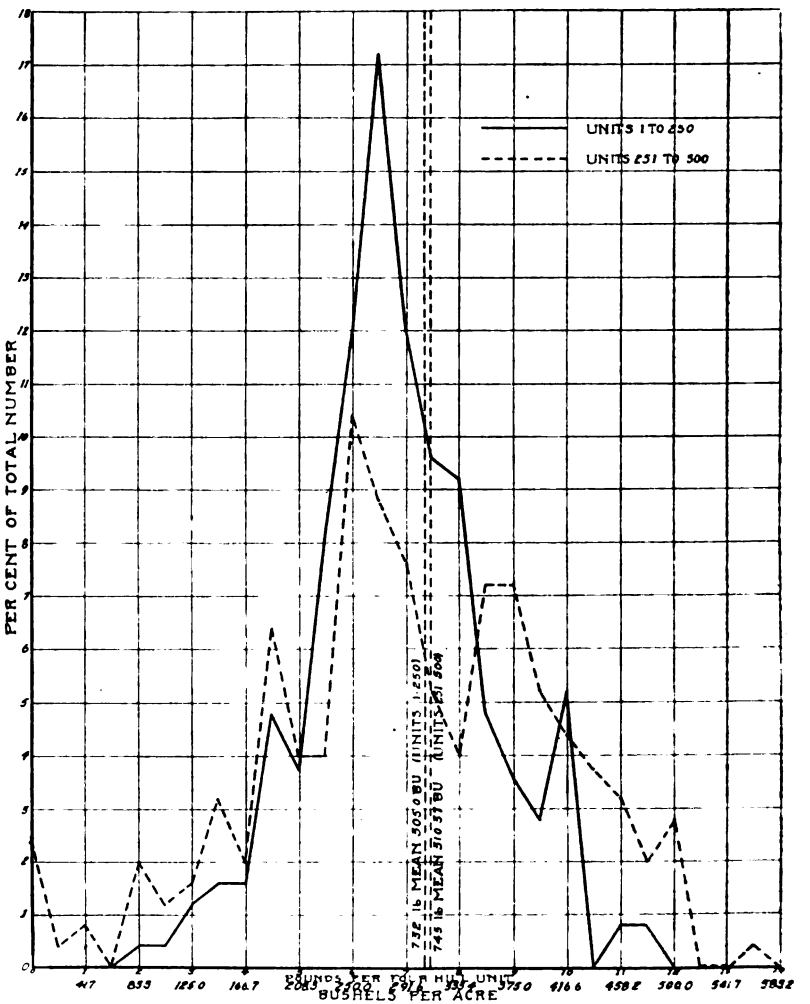

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TABLE 2—*Distribution of yield of marketable potatoes produced by 1000 tuber units of Pearl potatoes in Kimball County, 1917*

Variant or weight of marketable potatoes per 4-hill tuber unit	Frequency, or total number of tuber units producing a yield within the specified range			
	Irrigated plat (4)*		Dry land plat (3)	
	Irrigated since 1910 1-250	On dry land since 1910 251-500	Irrigated since 1910 501-750	On dry land since 1910 751-1000
Pounds (1)	(2)	(3)	(4)	(5)
0	0	6	3	0
0- .49	0	0	0	0
.50- .99	0	1	1	1
1.00- 1.49	0	2	1	2
1.50- 1.99	0	0	1	1
2.00- 2.49	1	5	7	9
2.50- 2.99	1	3	8	9
3.00- 3.49	3	4	19	19
3.50- 3.99	4	8	18	23
4.00- 4.49	4	5	37	41
4.50- 4.99	12	16	25	36
5.00- 5.49	9	10	40	33
5.50- 5.99	21	10	39	26
6.00- 6.49	30	26	32	21
6.50- 6.99	43	22	9	9
7.00- 7.49	30	19	6	7
7.50- 7.99	24	13	2	10
8.00- 8.49	23	10		5
8.50- 8.99	12	18		1
9.00- 9.49	9	18		
9.50- 9.99	7	13		
10.00-10.49	13	11		
10.50-10.99	0	9		
11.00-11.49	2	8		
11.50-11.99	2	5		
12.00-12.49		7		
12.50-12.99		0		
13.00-13.49		0		
13.50-13.99		1		
Mean	7.32 ± .081	7.45 ± .116	4.61 ± .068	4.63 ± .067

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—*Correlation of weight and number of marketable tubers per 4-hill tuber unit of Pearl po-es at Kimball in 1917, irrigated plat (4), seed stock irrigated since 1910, unit numbers 1 50. (See also Table 5.)*

Weight of marketable tubers per 4-hill tuber unit.

0- .49	.50- .99	1.00- 1.49	1.50- 1.99	2.00- 2.49	2.50- 2.99	3.00- 3.49	3.50- 3.99	4.00- 4.49	4.50- 4.99	5.00- 5.49	5.50- 5.99	6.00- 6.49	6.50- 6.99	7.00- 7.49	7.50- 7.99	8.00- 8.49	8.50- 8.99	9.00- 9.49	9.50- 9.99	10.00-10.49	10.50-10.99	11.00-11.49	11.50-11.99	Total
Number of tuber units falling into various number and weight groups																								
						2			1	1														4
											2	3	4											9
				1	1		1	1	2	3	5	2	2	1	1	1								21
						1	1	3	5	2	4	8	13	3	1		1							42
							1		2	2	4	8	7	9	6	3	1	1						44
										1	2	5	6	6	3	2	1	1		3				33
							1				3	2	4	3	3	6	4		2	2				30
									1		1	1	5	1	2	3	2	3	1	5			1	25
									1				1	2	3	3	2							14
												1		3	1	2	2		1	2		2		12
													1	1		1	2	2	1	2				10
																1								1
																		1					1	2
																			1					1
																			1					1
														1										1
				1	1	3	4	4	12	9	21	30	43	30	24	23	12	9	7	13		2	2	250

Mean weight per unit, 7.82 lbs. Number of tubers, 18.07.

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often elongated (Tables 6 and 8). In a few instances it was noted that there were both strong and weak plants within the same unit. The weak hills of such units had the tuber and top appearances just described. Link (1917), in making detailed notes on the vigor (Table 4) of the hills in the Pearl tuber unit planting, described the leaf condition of certain plants as "incipient curl," "curl," and "curly dwarf." *

TABLE 4—*Leaf condition and plant vigor notes on 1000 Pearl tuber units. Kimball County, 1917*

Disease or vigor group	Frequency, or total number of plants falling into any specific disease or plant vigor group			
	Irrigated plat (4)		Dry land plat (3)	
	Irrigated since 1910 1-250	On dry land since 1910 251-500	Irrigated since 1910 501-750	On dry land since 1910 751-1000
(1)	(2)	(3)	(4)	(5)
(a) No plants	4	58	52	41
(b) Curly dwarf	4	0	0	0
(c) Curl	5	0	0	0
(d) Incipient curl	53	142	101	90
(e) Very poor	1	6	2	11
(f) Poor	28	16	19	45
(g) Poor to fair	7	10	1	13
(h) Fair	46	27	106	159
(i) Fair to good	159	135	198	280
(j) Good	607	523	426	333
(k) Good to excellent	21	79	95	28
(l) Excellent	65	4	0	0

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5—*Relation of relative vigor and disease symptoms to total yield of various tuber units. Pearl, Kimball, 1917, (Plat 4,) Lots 1-250*

notes are given for individual hills. Weights were taken on 4-hill unit basis. This ac-
unts for some plants being marked as "no plant," even tho a tuber unit weight is shown. The
eight reported was produced by the plants of the unit which did grow. See also Tables
and 5.

t of marketable tubers produced by 4-hill tuber unit of which the plant was a member.

	0	0- .49	.50- .99	1.00- 1.49	1.50- 1.99	2.00- 2.49	2.50- 2.99	3.00- 3.49	3.50- 3.99	4.00- 4.49	4.50- 4.99	5.00- 5.49	5.50- 5.99	6.00- 6.49	6.50- 6.99	7.00- 7.49	7.50- 7.99	8.00- 8.49	8.50- 8.99	9.00- 9.49	9.50- 9.99	10.00-10.49	10.50-10.99	11.00-11.49	11.50-11.99	Total
	Number of plants falling into various tuber unit weight groups																									
plants.....	4										2		1		2	8										17
ly dwarf.....								4									1									4
l.....										4																5
pient curl...						4	4	8	8	12	5		1		3		3	4				4				56
y poor.....																1										1
r.....									5		3		1	8	2		2	3	3	1						28
r to fair.....											3		1			1	1			1						7
.....											1	2	3	9	7	8	2	2	2	4	1	5				46
to good....									3		5	12	25	28	41	13	9	13	2	3	1	6				161
d.....											29	22	42	73	114	77	79	66	23	15	20	24		5		589
d to excellent														2	3	8			4	4						21
ellent.....													6			8	3	4	6	8	6	13		3	8	65
Total.....	4					4	4	12	16	16	48	36	80	120	172	124	100	92	40	36	28	52	0	8	8	1,000
	Mean weight per unit, 7.32 lbs.																									

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At digging time it was found that these abnormal leaf characteristics were associated with the weak units. The correlation between vigor and plant yield is shown in Table 5.

TRIALS IN 1918

The work for 1918 was planned with a view of determining the extent to which unit differences are transmitted to the next generation and the frequency with which weak units might appear from a vigorous tuber line strain. Accordingly the tubers of a number of the weak, moderately weak, and

TABLE 6—*Relation of vine vigor and yield to tuber type, yield, and leaf condition, the preceding year*
(Pearl tuber units, 1917-1918,—Plats 3 and 4.)

Unit number	1917			1918	
	Leaf condition	Yield per plant	Tuber type	Vine vigor	Yield per plant
(1)	(2)	*Pounds* (3)	(4)	(5)	*Pounds* (6)
			DRY LAND PLAT (NO. 3)		
(a) 531	"Incipient curl"..	.63	Poor, slightly elongated.	Uniformly poor.....	.819
(b) 568	"Incipient curl"..	.56	Elongated.....	Uniformly poor.....	.125
(c) 595	"Incipient curl"..	.56	Small, slightly elongated	Uniformly poor.....	.....
(d) 883	"Incipient curl"..	.50	Poor, elongated.....	Uniformly poor.....	.....
(e) 917	"Incipient curl"..	1.87	Medium poor.....	Poor to good.....	.....
(f) 923	Healthy check....	1.87	Good.....	Uniformly very good.	1.91
(g) 925	Healthy check....	1.95	Fairly good.....	Uniformly very good.	1.98
			IRRIGATED PLAT (NO. 4)		
(h) 13	"Curl".....	1.00	Poor.....	All poor.....	.47
(i) 19	"Curly dwarf"...	.81	.....	All poor.....	.79
(j) 37	"Incipient curl"..	1.00	Poor.....	All poor.....	.83
(k) 89	"Incipient curl"..	.9	Poor.....	All poor.....	.....
(l) 176	"Incipient curl"..	1.00	Poor.....	Very poor.....	.....
(m) 181	"Incipient curl"..	.80	Elongated.....	Very poor.....	.....
(n) 325	"Incipient curl"..	1.00	Medium poor.....	Very poor.....	.....
(o) 362	"Incipient curl"..	1.30	Much elongated.....	All poor.....	1.03
(p) 370	"Incipient curl"..	.75	Poor.....	All poor.....	.....
(q) 395	"Incipient curl"..	1.06	Poor.....	Very poor.....	.....
(r) 459	"Incipient curl"..	.56	Poor.....	Very poor.....	.....
(s) 20	Healthy check....	2.75	Good.....	All good.....	2.32
(t) 46	Healthy check....	2.44	Good.....	All good.....	3.53
(u) 369	Healthy check....	2.75	Large, fair.....	All good.....	1.94

strong units of 1917 were saved separately and planted. Each tuber of these units was cut into seed pieces of similar size, which were planted consecutively in the row. By having a label separating the hills of each tuber and another separating the progenies of the different units, it was possible to determine the behavior of each tuber of a unit as well as that of the tuber-unit line as a whole.

Upon harvesting this material it was found that all hills from weak units were weak. On the other hand, there was

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TABLE 7—*Four years' results from various tuber line strains of Pearl potatoes, grown at Kimball, under irrigation*

Unit No.	1917			1918				1919					1920		
	Four-hill tuber units			No. of hills	Mean vigor	Yield per acre		No. of hills	Mean vigor	Mean per cent of disease	Yield per acre		No. of hills	Mean vigor	Total yield per acre
	Mean vigor	Disease	Total yield per acre			U. S. Grade No. 1	Total yield				U. S. Grade No. 1	Total yield			
(1)	*Per cent* (2)	(3)	*Bushels* (4)	(5)	*Per cent* (6)	*Bushels* (7)	*Bushels* (8)	(9)	*Per cent* (10)	*Per cent* (11)	*Bushels* (12)	*Bushels* (13)	(14)	*Per cent* (15)	*Bushels* (16)
13	30	IC	166.6	25	12	80.1	100.2	88	12.6	100.0	0	3.0	.....	.....	.....
14	94	0	426.5	20	90	528.0	565.6	618	61.7	43.0	48.1	62.3	455	26.8	52.4
19	25	CD	135.6	24	15	104.1	131.8	164	20.2	77.8	0	4.8	.....	.....	.....
20	94	0	456.5	105	70	385.1	409.8	200	57.3	46.2	35.5	45.3	180	52.5	102.9
37	30	IC	166.6	26	15	111.7	137.9	196	8.0	100.0	0	3.0	.....	.....	.....
46	94	0	406.2	28	95	.....	588.3	.....	.....	.....	.....	.....	.....	.....	.....
50	65	0	413.3	64	80	.....	441.3	.....	.....	.....	.....	.....	.....	.....	.....
362	25	IC	218.7	44	30	.....	171.7	.....	.....	.....	.....	.....	.....	.....	.....
369	75	0	458.3	63	75	326.7	347.7	304	54.5	37.6	63.6	90.5	200	58.1	110.7
374	75	0	446.9	28	85	.....	528.3	.....	.....	.....	.....	.....	.....	.....	.....
483	90	0	343.2	95	70	373.8	389.2	276	63.5	49.4	63.9	90.3	200	54.6	97.1
500	85	0	291.6	80	75	328.5	346.7	303	59.1	28.1	58.7	80.8	200	61.1	110.2
923	Healthy strain grown on dry land prior to 1919. Bin run from original stock irrigated since 1917.							340	75.1	3.6	71.7	91.9	160	48.5	89.6
											.....	76.7			

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a difference in the behavior of the progeny of formerly strong units. A few produced uniformly strong plants while others gave both strong and weak plants (Table 8). In most instances where strong units produced weak plants, all hills from a given tuber were affected. In a few instances, however, as in 1917, both strong and weak hills appeared from the same tuber. The behavior of 3 Pearl units is shown in figure 9. Unit 362 was a poor unit in 1917 and its progeny was weak in 1918; unit 374 was strong and its progeny was strong; while the progeny of the strong unit No. 50 produced both strong and weak units. Other data are shown in Table 6 to further illustrate the performance of good and poor unit strains. Tubers from plants marked as showing "curl," "curly dwarf," and "incipient curl" gave progenies which the next year were uniformly poor with regard to vine vigor, plant yield, and tuber type.

Seed stock was saved from several of the uniformly vigorous Pearl units in 1918 for future study. Within 3 years, however, all of these had broken up and produced nothing but weak strains (Table 7). The rapidity with which this took place is illustrated in figure 10, the tubers in each pile being the product of 10 hills in 1920. The two 10-hill lots were grown adjacent to each other and came from adjacent hills of the same tuber unit in 1919.

The behavior of the irrigated Triumph units in succeeding years was similar to that of the Pearls (Table 8). The per cent of weak units was greater in this Triumph stock (fig. 5) in 1917 and the strong units later broke up more rapidly and more completely. The weak units of this stock when planted on dry land at Alliance in 1918 continued weak. In 1918 and 1919, vigorous units from dry land were planted under irrigation together with vigorous units from irrigated stock. The dry land stock did not break up as rapidly as irrigated stock.

In addition to the vigor differences of the units noted

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degrees of severity, and that stock affected with it becomes progressively more degenerate. Irrigated stock, as indicated by the trials already referred to and others to be mentioned later, seems to be affected more severely than dry land seed.

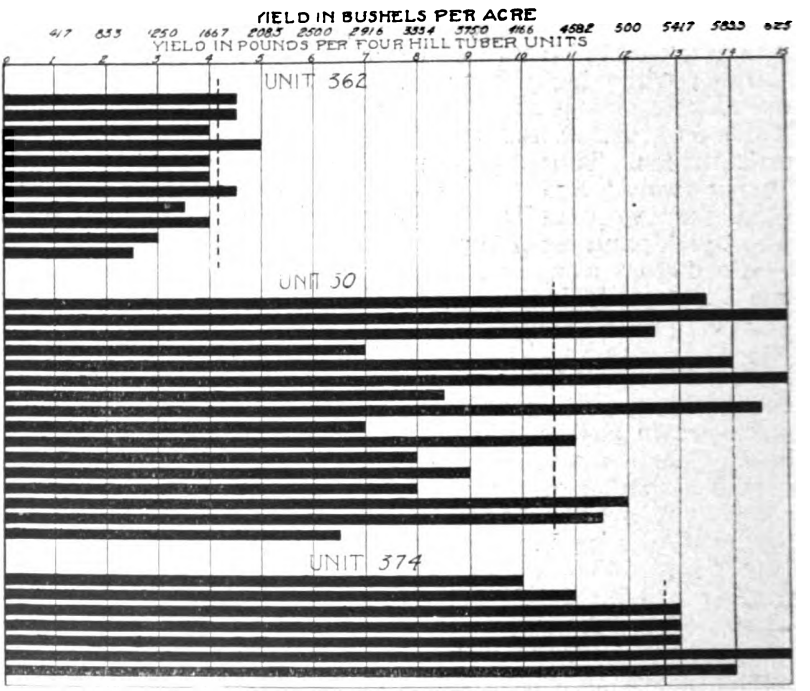

FIG. 9.—Behavior of progeny of 3 Pearl tuber units produced in a field containing a number of degenerate plants. Each bar represents yield produced by a 4-hill tuber unit in 1918, from one of the tubers produced in the 1917 4-hill tuber unit. Unit 362 yielded below the mean in 1917 and produced elongated tubers. It produced only poor plants and poor tubers in 1918. Unit 50, which was a high yielding unit in 1917 (fig. 7), started to break up into good and poor units in 1918. Unit 374, which was high yielding in 1917, continued to be high yielding in 1918 without any indications of breaking up (Table 7). (This difference in the behavior of units 50 and 374 is probably due to difference in their relative proximity to degenerate units in 1917.)

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TABLE 8.—*Relation of yield to tuber type and to vine vigor in progeny in "running out" strain of Triumph potatoes. Also relation of proximity of "run-out" and vigorous tuber units to rate of degeneracy of normal units. Scotts Bluff County, irrigation (Plat 9), 1917, 1918*

Unit No.	1917		1918	
	Yield per 4 hill tuber unit	Tuber type	Type of vine growth or vine vigor*	Relative vine vigor*
(1)	*Pounds* (2)	(3)	(4)	*Per cent* (5)
81	16.00			
82	16.50	Good	Very good to very poor	45
83	16.25			
98	16.50			
99	2.25	Elongated, light colored	Uniformly very poor	10
100	10.00			
134	3.25			
135	7.75	Elongated, light colored	2% P—; 20% P; 27% M—; 34% M; 9% G—; 8% G	48.9
136	20.75			
161	19.25			
162	17.50	Good type		
163	9.00			
172	3.50			
173	17.75	Good type	Very good to very poor	60
214	12.75			
215	19.50	Good type	9% P; 30% M; 3% M+; 18% G; 10% G+	55.6
216	15.00			
253	2.25			
254	16.25	Some light colored and pointed	10% P—; 10% P; 30% M; 30% M+; 10% G; 10% G+	55.9
255	3.00			
277	3.50			
278	13.50	Some good, some elongated	10% P—; 20% P; 30% M—; 10% M; 25% G; 5% G+	50
279	2.50			
290	2.50			
291	15.25	Light colored, elongated	Medium to poor	31.2
292	3.00			
310	5.50			
311	3.50	Elongated, light colored	All poor	25
312	16.75			
325	3.50			
326	1.25	Light colored, elongated	All very poor	5
327	2.75			
357	16.00			
358	15.75	Large, good	Very good to very poor	50
359	4.25			
365	3.25			
366	17.50	Good	Very good to poor	60
367	16.50			
449	7.00			
450	13.75	Irregular, knotty	Uniformly good	80
451	Not Recorded			

*Arbitrary percentage value for plant vigor symbols in 1918. P— 12.5; P 25; M— 37.5; M 50; M+ 62.5; G— 75; G 87.5; G+ 100%.

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COMPARISON WITH OTHER DEGENERATION DISEASES

The most common type of degeneracy found in western Nebraska may be described as follows:

TUBER CHARACTERISTICS

Shape.—Long, cylindrical, and pointed at the bud end. In mild cases tubers are only slightly elongated and more blocky than normal. In very extreme cases the tubers are sometimes very ill-shaped and crooked (figs. 13, 14, 19, 21, 22). Flat varieties become cylindrical and much elongated

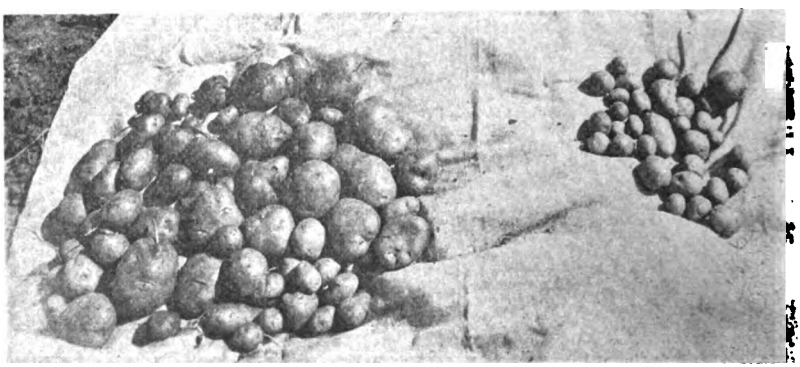

FIG. 10.—At left, product in 1920 of 10 Pearl hills from one 1919 hill,—14-4-19; at right, product of 10 hills from adjoining 1919 hill of same unit,—14-4-20. Unit at left yielded 120 bushels per acre; unit at right, 29.3 bushels. Note high per cent of small and run-out tubers in pile at right.

(fig. 13). Tubers are very subject to growth cracks but are seldom knobby. Stolons are thickened, from 3 to 4 times the diameter of normal stolons.

Size.—The size is frequently reduced, tho not always.

Color and texture of skin.—The color of the skin of red or pink varieties is distinctly lighter than that of normal tubers and very commonly is yellowish or blotched. The skin

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later than normal. Rudimentary leaflets are frequently produced on the newly formed tubers toward the end of the growing season.

PLANT CHARACTERISTICS

General habit of growth.—The plants lack vigor. They are erect, stiff, and spindling, with very few stems per hill. Stems have practically no lateral branches (figs. 12 and 20).

Leaves.—Are smaller and generally somewhat darker in color, with an erect, stiff appearance. They are folded upward slightly along the midrib and have a distinct waving of the margin. These are the first symptoms noticed on slightly affected plants.

Flowers.—Conspicuous because the blossom stems are stiff and more erect, generally extending above the leaves more than in normal plants. Degenerate plants have a tendency to bloom more profusely and to produce more seed balls. The dead blossoms adhere to degenerate plants longer than to normal plants. The naked blossom stems are much in evidence on spindling tuber plants until the end of the growing season.

These symptoms characterize plants in the extreme stages of degeneracy. Early stages are difficult to detect. Plants apparently normal may produce tubers showing "run-out" symptoms. Likewise, apparently normal good type tubers may produce plants with symptoms of degeneracy. On the other hand, tubers showing distinct degeneracy symptoms never produce normal plants.

It will be noted that this description does not correspond to that in published reports of mosaic, leaf roll, spindle sprout, and several of the other diseases considered as degeneration diseases. It does, however correspond very closely to that given for spindling tuber (Shultz and Folsom, 1923; and Folsom, 1923), and is somewhat similar to a type of degeneracy found and illustrated by Stewart (1916) but without special comment.

This spindling tuber type of degeneracy differs primarily from mosaic (as commonly understood) and leaf roll, in that it does not cause a mottling or crinkling of the leaves, nor has a net necrotic condition of the tubers been observed. It also differs from these 2 diseases in that the tuber type is distinctly influenced. The work reported herein suggests that the mode of transmission of this degeneracy trouble is similar to that of mosaic, which is tuber borne and insect transmitted.

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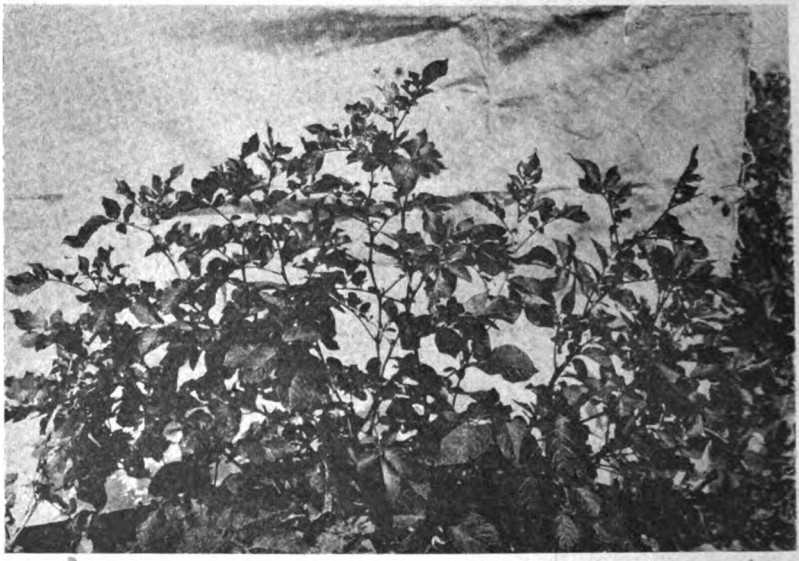

FIG. 11.—Normal type of Downing potato plant, grown at Bayard (6), 1920. Note large number of flexible stems, spreading habit of growth, flat smooth leaves and relatively inconspicuous flowers. For tubers produced by this type of plant see figure 13 (at left).

FIG. 12.—Degenerate type of Downing potato plant grown at Bayard (6), 1920. Note stiff, erect stems, compact habit of growth, stiff, folding leaves with wavy margin, also numerous and conspicuous flower clusters. For tubers from this type of plant see figure 13 (at right).

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FIG. 13.—Good and poor type, Russet Rural New Yorker potatoes raised at Morrill (13), in 1920. At left, good type tubers, the product of one 4-hill tuber unit with normal plants (similar to fig. 11); total yield from unit, 10.9 lbs. At right, elongated run-out type tubers, the product of another 4-hill tuber unit with abnormally degenerate type of plants (similar to fig. 12); total yield from unit, 7.4 lbs.

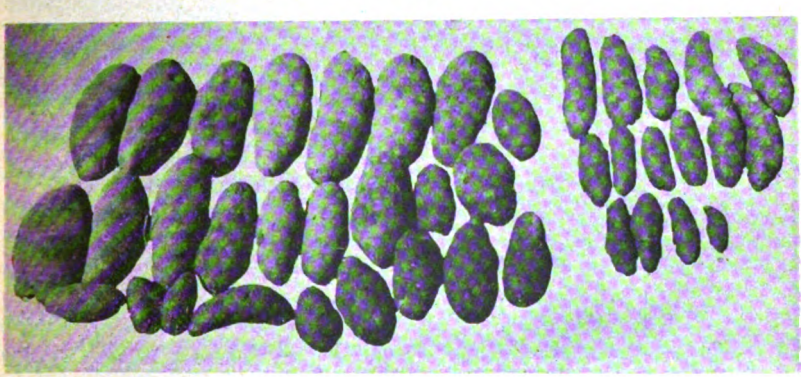

FIG. 14.—Normal and run-out tuber units of Russet Burbank potatoes, Morrill (13), 1920. Yield of normal unit 12.7 lbs., of run-out unit 2.9 lbs.

PREVALENCE OF DEGENERACY

The type of degeneracy described above has been found in in all experimental plats and in many fields in all parts of

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land regions, and some varieties have been practically eliminated, so far as commercial culture is concerned (Janssen, 1919; Sheldon, 1920).

EFFECT OF DEGENERACY UPON VIGOR, TYPE, AND YIELD

Correlations of the various symptoms of the type of degeneracy described were noted as the original selected tuber line lots were grown during succeeding years and as other

TABLE 9—*Relation of vigor of vine growth to type of tubers produced. Distribution of 114 4-hill Triumph tuber units. Bayard (9), 1920*

(Highest development of tuber type or vine vigor indicated by 10, lowest by 1, intermediate stages given relative values.)

	Relative tuber type (numerical value)										
Vigor of vine (numerical value)	1	2	3	4	5	6	7	8	9	10	Total number of each vigor group
	Number of units within each group										
10				1	1	3		4			9
9			4		5	8	16	4	1		38
8	1		1	1		3	5	1			12
7	1	4				1	2				8
6	4	10	1	1							16
5	8	2	1		1		1				13
4	8	2									10
3	2		1								3
2	4										4
1	1										1

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lines of investigation were inaugurated. Very definite correlations between vigor of vine, type of tuber, and yield of tubers (or tuber production) were observed.

In 1920, 114 Triumph tuber units were planted near Bayard (Plat 7) with tubers selected from that many high yielding hills in a plat on the same farm in 1919. The plants and tubers of each unit were scored on a numerical basis for both vine vigor and tuber type, using 1 for the lowest and 10 for the highest relative development. The original plants scored high on type and vigor. The variation in vine vigor

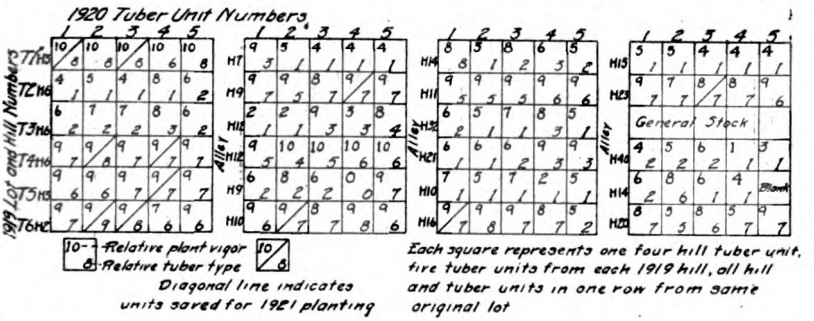
1920 Tuber Unit Numbers
1919 Lot and Hill Numbers
Alley
General Stock
Plank
10 Relative plant vigor
8 Relative tuber type
Diagonal line indicates units saved for 1921 planting
Each square represents one four hill tuber unit, five tuber units from each 1919 hill, all hill and tuber units in one row from same original lot

FIG. 15.—Field location in 1920, at Bayard (6), of various tuber units raised from 1919 hill selections of Triumph potatoes; also relative plant vigor and tuber type of each 4-hill unit. Tuber type of vigorous units was best, but was lowered when units grew in close proximity to weak run-out units. (See Table 9, also figs. 16 and 23.)

was from 1 to 10 and in tuber type from 1 to 9 (Table 9). When the vine vigor was below 8 the plants generally showed some of the distinct degeneracy symptoms. When the tuber type scored below 7 the symptoms of degeneracy in the tubers were not all apparent but the tubers were generally considerably elongated. However, when the tubers scored below 5 a number of the symptoms were distinctly in evidence. The exact 1920 field location of each of these 114 units, together with the relative plant vigor and tuber type score for each unit, is shown in figure 15. (This figure will be referred to later, in connection with field transmission studies.) A very distinct correlation between good tuber type and good vine vigor was discovered. Vigorous plants produced the better type tubers, while the plants of low vigor almost invariably produced only poor type tubers. (See Table 9, also fig. 18, fig. 22 and Table 6.) Both Table 9 and fig. 15 show that the decline in tuber type was greater than in vine vigor.

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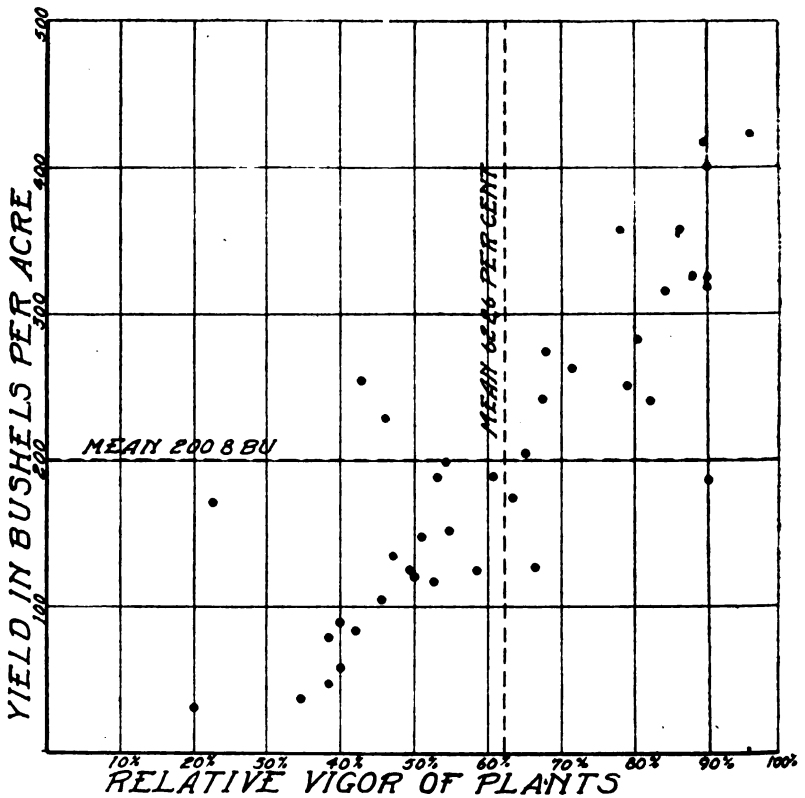

FIG. 16.—Correlation of plant vigor to rate of yield. Triumph tuber units, Bayard (6), 1920. (For field location of units, see fig. 15; for vigor and tuber type, see Table 9.)

It is evident that this group of units was degenerating rapidly and that such degeneracy was more evident in the tuber type than in the vine vigor.

The yield records secured for 40 of the 1920 Triumph units in the Bayard plat showed a very direct correlation between high plant vigor and high yield of tubers (fig. 16). Very poor yields were secured from the units of low plant vigor. The loss here from an economic standpoint was twofold, for it has just been shown (Table 9 and fig. 15) that these plants of low vigor also produce only poor type tubers. Similar results with Pearl unit selections in Kimball County in 1920 are shown in figure 17. (See also Tables 5, 6, and 7.)

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Data concerning the correlations existing among poor yielding units, when due to degeneracy (as shown by poor type), are presented in Table 10 for 90 Downing units grown in Scotts Bluff County in 1920. (For application to Triumph variety see also fig. 18 and fig. 22.) The data in Table 11 are further evidence on this point, applying to 5 varieties, grown with irrigation in one case and on dry land in the other.

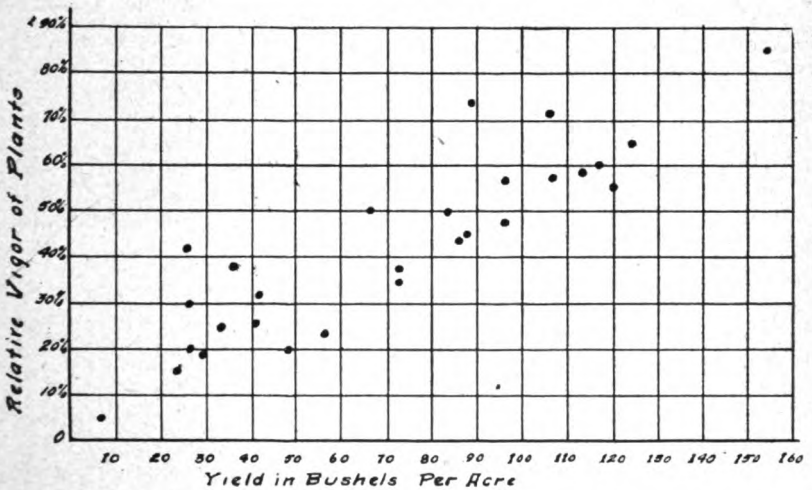

FIG. 17.—Correlation of vine vigor and total yield of tubers,—in bushels per acre in 29 tuber line strains of Pearl potatoes. The yield is in direct ratio to the vigor of the vine. (Irrigated plat at Kimball (4), 1920.)

EFFECT OF CULTURE AND PLACE UPON DEGENERACY

The general condition of the seed potato stocks in the irrigated regions of western Nebraska has been very unsatisfactory. It has been common experience that good new stock would produce high yields for 1 or 2 years, after which the yield and tuber type rapidly deteriorated. During recent years, dry land grown seed has been found to give satisfactory results. Trials have shown that as a class irrigated seed does not yield as well as dry land seed. (Werner, 1920, 1921.) This has also been borne out by the experience of practical growers (Janssen, 1919; Sheldon, 1920, 1921; Parrish, 1921;

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TABLE 10—*Relation of tuber type and yield per 4-hill tuber units. Distribution of 90 tuber units of Downing potatoes. Scotts Bluff (10), 1920*

Relative tuber type (numerical value)	Total yield per four-hill unit (in pounds)														Total number in each tuber type group
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
10															
9											1				1
8								1	1		1	2			5
7							2	1	4	3	2		1	1	14
6				1		1	1	1	2	5	2			1	14
5							1		2						3
4			1	1	1			2	2		1	1			9
3			1	1	4	4	1	2		1					14
2		3		1	5	1	1	3	1		1				16
1	1	1	2	2	3	2	1	2							14
Total number of each yield group	1	4	4	6	13	8	7	12	12	9	8	3	1	2	90

Ehrman, 1921). Some preliminary reports have shown that additional years of culture under irrigation aggravate this condition (Werner, 1920, 1921).

Other investigators have reported upon the behavior of dry land and irrigated seed potatoes. Schollander in North

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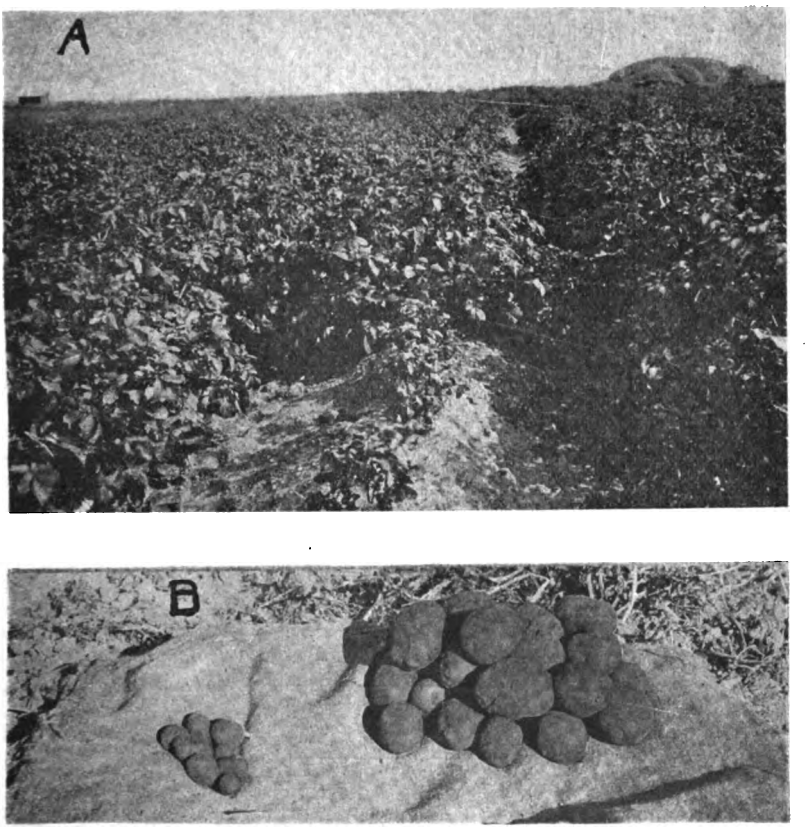

FIG. 18.—Relation of vigor of vine growth to tuber type and yield. Also characteristic tuber unit behavior of running out seed stock. Triumph potatoes, Bayard (6), 1920. A, plants of T2H12U2 in center of foreground, T3H12U3 in background, to left T2H9U2, and to right T4H10U2. B, actual yield of tubers,—T3H12U2 at left, T3H12U3 at right. (See fig. 15 for relative location.)

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n of tuber type to yield in tuber units of several varieties grown at Morrill (13) (irrigated) and at Bushnell (5) (dry land), 1920

merical basis 1 to 10. Yield per 4-hill tuber unit in pounds. Seed stock was originally from the same source, in 1919.

ıracter described	Tuber unit number										Mean of each variety
	1	2	3	4	5	6	7	8	9	10	
(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
MORRILL PLAT (13), IRRIGATED SEED, GROWN AT MORRILL 1919											
ɔer type	9	8	8	9	8	8	2	1	7	2	6.2
t yield	8.0	8.5	10.6	9.8	9.3	9.0	4.8	3.1	8.5	1.2	7.28
ɔer type	7	2	5	7	8	8	8	9	2	4	6.0
t yield	8.9	4.2	7.2	5.4	5.7	5.5	7.4	8.4	5.2	4.8	6.27
ɔer type	7	2	1	7	6	7	2	1	7	1	4.1
t yield	15.5	6.1	5.9	10.7	10.0	11.0	7.3	5.9	11.5	5.1	8.60
ɔer type	2	7	1	2	1	2	2	1	1	2	2.1
t yield	3.5	6.6	6.5	7.1	3.7	8.0	8.3	7.4	7.0	8.3	7.06
ɔer type	4	7	4	4	5	2	2	2	2	7	3.9
t yield	10.6	9.7	6.5	6.5	14.1	7.9	8.4	4.5	6.7	13.2	8.81
BUSHNELL PLAT (5), DRY LAND SEED, GROWN AT BUSHNELL 1919											
ɔer type	9	9	9	9	10	8	8	9	8	8	8.7
t yield	3.4	2.1	3.0	3.3	3.3	1.4	2.2	3.0	3.3	2.9	2.79
ɔer type	7	7	8	6	5	8	7	9	6	.....	7.0
t yield	3.0	3.4	3.3	2.3	2.1	2.9	2.4	4.9	2.1	.....	3.04
ɔer type	9	9	9	10	9	9	9	8	9	8	8.9
t yield	4.3	3.4	4.7	5.3	3.3	3.4	3.3	4.9	5.3	2.5	4.24
ɔer type	9	3	6	8	1	6	7	7	9	10	6.6
t yield	5.1	2.1	5.4	4.6	2.3	2.3	4.2	5.3	3.7	4.7	4.02
ɔer type	4	6	7	9	9	7	7	7	8	6	7.3
t yield	3.3	6.2	4.9	6.6	5.5	3.9	4.3	3.7	5.5	4.3	4.82

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The Nebraska results cannot be interpreted to correspond entirely to those of the above investigations, since degeneracy has been found to be more prevalent in irrigated stock, and affected plants or tubers never recover to the point of giving satisfactory yields; and, furthermore, the best seed stock has been grown on dry land. It is believed that irrigation as such is not the cause of the degenerate condition herein described, but that the growing conditions afforded by irrigation are more conducive to the development of degeneration diseases. Since this type of degeneracy appears to be similar to mosaic in its mode of transmission, this assumption seems to be

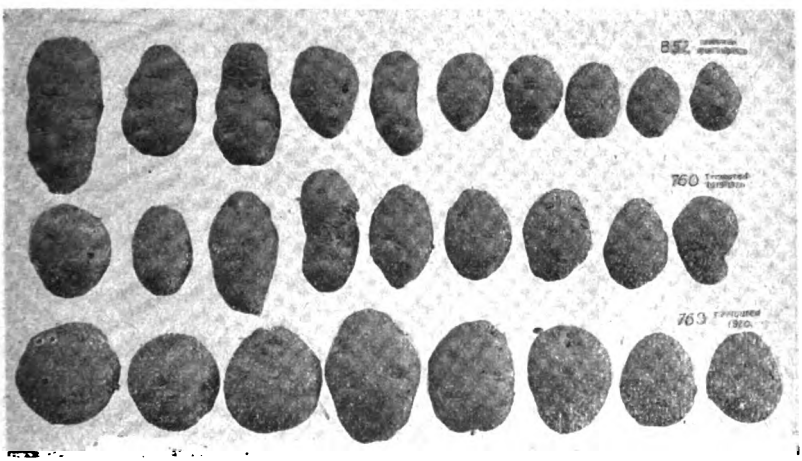

FIG. 19.—Tuber types from strains of potatoes in various stages of degeneration, in Scotts Bluff County (Plat 9), 1920. Lower row grown from new dry land seed from Alliance (Plat 14). Middle row grown in Scotts Bluff irrigated plat one year. Top row grown in irrigated plat two years. Note increased elongation and roughness, also more numerous and more shallow eyes. All stock was grown in irrigated plat containing degenerate strains. Two lower rows are from same original tuber in 1917.

in accord with the work of Elmer (1922), who reported that infection with mosaic was most easily accomplished when growing conditions were such as to produce an unchecked, vigorous growth.

Carefully conducted experiments with tuber line strains from irrigated and dry land stock were made at Kimball, Alliance, Minatare, Bayard, and Mitchell to determine the relation of irrigation practice to degeneracy (no degenerate

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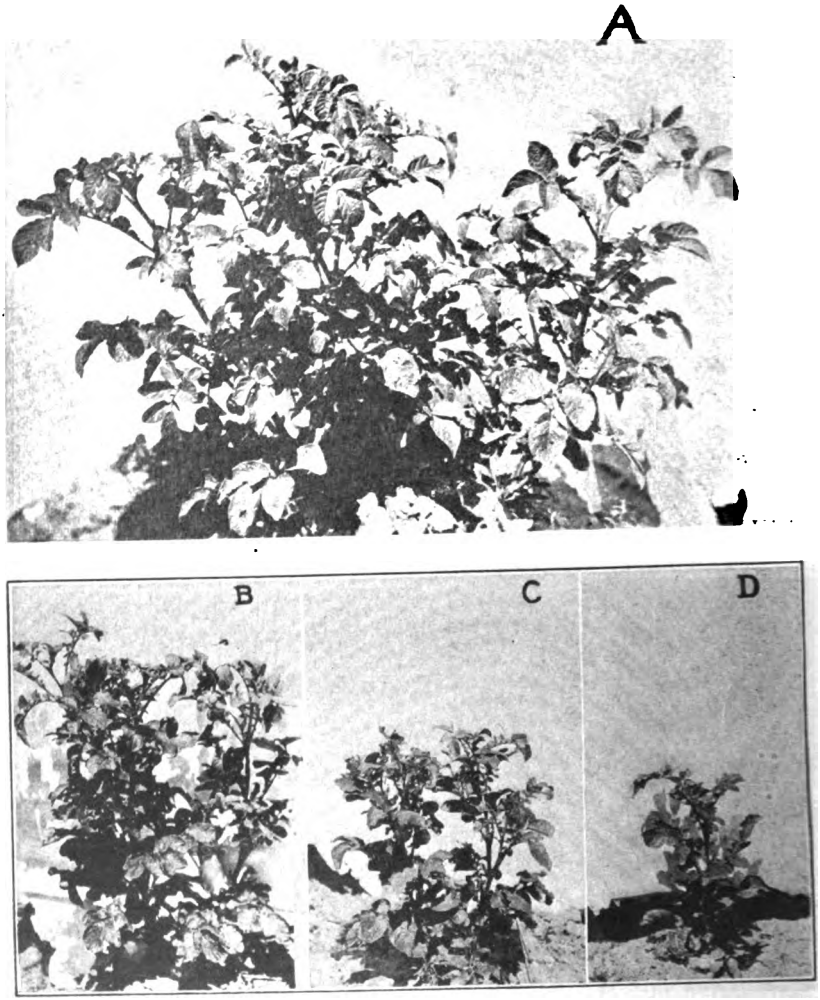

FIG. 20.—Types of Triumph potato plants from normal, **A**, to extreme degenerate condition, **D**,—produced in Scotts Bluff County, 1921, under irrigation (Plat 11). Note tendency for degenerate plants to become smaller, more erect, with fewer stems, also folding of leaves with waving along margin. (Tubers in fig. 21.)

FIG. 21.—Tubers produced by plants shown in figure 20. Note smaller yield, elongation of tubers, and greater number of small tubers, as degeneration increases.

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plants being removed from the plats). Similar tests were made at Morrill, 1920 to 1922, with dry land and irrigated seed of 10 different varieties.

The high yielding Triumph units from the 1917 Alliance tuber unit plat (dry land) were planted the following year under irrigation in Scotts Bluff County. Their average yield was at the rate of 403.7 bushels per acre, or approximately 4 times as great as the yield secured from several units selected from the 1917 irrigated plat. The yields of these dry land lots decreased very materially under irrigation. A very large number of degenerate plants were present in these irrigated plats. (Table 12, columns 3, 4, 5, 6.) In 1921 some of the stock irrigated 3 years was planted on dry land. The yield from this stock when planted under irrigation (123.2 bu.) was 28.6 per cent greater than that of the same strain grown for 4 consecutive years with irrigation (91.3 bu.). (Table 12, columns 7, 6.)

In 1919 one-half of the tubers of each of 2 other tuber line strains from the dry land plat at Alliance were planted under irrigation, and the remaining tubers retained under dry land culture. This was repeated for 3 years. Seed stock was also saved each year from the irrigated plat. The yields decreased with each succeeding year of irrigation when compared with fresh dry land seed (Table 12, columns 4, 5, 6). Some of this stock was also grown on dry land after 1 and 2 years' irrigation and then planted in comparison with irrigated (1, 2 and 3 years) and fresh dry land seed. When irrigated stock was grown 1 year on dry land it gave an increased yield in comparison with continuously irrigated seed, but the apparent rejuvenation was far from complete, since its production was less than 50 per cent of that of fresh dry land seed (Table 12, columns 6, 7). Some of this recovery is probably due to the fact that the dry land conditions of the 1921 plat were very severe, resulting in most of the weak plants being killed early in the season. It is probable, therefore, that only the stronger units of this plat were used as seed. This natural selection did not maintain for the irrigated stock, because here even the weaker units produced tubers of seed size.

The decreased yields referred to in these tests were due to the type of degeneracy previously described, since they were accompanied by the progressive deterioration in vine and tuber type shown in figs. 19, 20, and 21.

The influence of irrigation practice upon seed value is

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TABLE 12—*Degeneration of normal dry land tuber unit lots of seed potatoes (when planted in an irrigated field containing degenerate lots) as manifested by reduction of total yield*

All seed originally from dry land tuber unit plat at Alliance (14) in 1917. Dry land stock used in 1918 to 1921 grown in Alliance (14) plat. Dry land stock used in 1922 grown in Scottsbluff plat (12). All yields reported were secured in irrigated plats. To note degeneracy of any lot thruout succeeding years, read horizontally. To note relative value of lots of seed in same year, read vertically, comparing with dry land lots at bottom of column.

Original unit, number in Alliance dry land plat in 1917	Results from lots of seed from various sources during each year					
	Trials at Minatare			Trials at Scotts Bluff Exp. Farm		
	1918	1919	1920	1921	1922	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Previous culture of seed tubers..	Dry land	Irrigated 1 year	Irrigated 2 years	Irrigated 3 years	Irrigated 4 years	Irrigated 3 years, dry land 1 year
545	518.1 bu.	103.3 bu.	21.9 bu.	.....	.....	.....
560	454.9 bu.	80.0 bu.	56.0 bu.	58.4 bu.	98.5 bu.	143.3 bu.
580	283.6 bu.	60.0 bu.	46.1 bu.	103.3 bu.	139.2 bu.	184.0 bu.
852	255.7 bu.	152.0 bu.	21.9 bu.	53.4 bu.	82.5 bu.	.....
855	441.0 bu.	110.0 bu.	35.2 bu.	55.0 bu.	44.8 bu.	101.3 bu.
856	506.7 bu.	76.0 bu.	14.2 bu.	.....	.....	64.3 bu.
Mean of all lots in trial	403.7 bu.	108.3 bu.	32.9 bu.	44.3 bu.	91.3 bu.	123.2 bu.
Per cent of yield produced by dry land lots same year	100%	39.2%	11.5%	22.2%	34.2%	46.2%
Previous culture of seed tubers..	.....	Dry land	Irrigated 1 year	Irrigated 2 years	Irrigated 3 years	Irrigated 2 years, dry land 1 year
553	.....	246.7 bu.	70.1 bu.	90.8 bu.	49.0 bu.	126.7 bu.
760	.....	306.6 bu.	79.8 bu.	69.6 bu.	45.1 bu.	75.3 bu.
Mean of both lots	.....	276.5 bu.	74.9 bu.	80.2 bu.	47.1 bu.	101.0 bu.
Per cent of yield produced by dry land lots same year	.....	100%	26.8%	40.4%	17.6%	37.8%
Previous culture of seed tubers..	.....	.....	Dry land	Irrigated 1 year	Irrigated 2 years	Irrigated 1 year, dry land 1 year
553	.....	.....	276.5 bu.	195.7 bu.	186.7 bu.	168.0 bu.
760	.....	.....	321.6 bu.	173.3 bu.	67.9 bu.	89.6 bu.
Mean of both lots	.....	.....	276.1 bu.	189.5 bu.	127.3 bu.	128.8 bu.
Per cent of yield produced by dry land lots same year			100%	94.0%	47.7%	48.2%

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further emphasized by the trials with different varieties. In 1919 the original seed of 10 varieties was secured from various sources in the north and west. Each variety was divided into a number of small lots, which were distributed to the trial plats located at various places. Each year a representative lot of good type seed was selected from all varieties in each trial plat. Some of this material was shipped to a central point for storage, to be used in a comparative plat on an irrigated farm near Morrill. By this means it was possible to compare the same original stock of 10 varieties after it had been grown from one to three years under irrigation and on dry land. Each variety was planted in a separate row in all plats. The planting order in each of the plats was: Triumph, Early Ohio, Irish Cobbler, Downing, Pearl, Rural New Yorker, Russet Rural New Yorker, Green Mountain, Russet Burbank, and King. All of these were good vigorous strains except the Triumph and Irish Cobbler. These were retained, but more satisfactory strains of these 2 varieties were later included. The results from seed potatoes produced at Bushnell (dry land) and Morrill (irrigated) are shown in Table 13. Dry land stock when planted under irrigation produced a greater total yield than any lots of the same variety originally from dry land but given 1 to 3 years of irrigated culture. Each additional year of irrigation resulted in a relatively greater decrease in total yield of every variety. The market quality was also poorer in all lots from irrigated seed. In 1922 the degenerate or "run-out" (elongated, light colored) tubers of No. 1 size were weighed separately. The percentage of these tubers appearing in the different lots is shown in column 23, Table 13. With a single exception the dry land stock produced a smaller proportion of run-out tubers than any of the irrigated lots of the same variety. This degeneracy increased quite regularly with each additional year of irrigation. Thus, the mean per cent of degenerate tubers for all dry land lots was 9.7, after 1 year of irrigation 29.4, and after 3 years of irrigation 44.9. The No. 2's and culls contained even a larger percentage of run-out tubers. There was also an increase in the per cent of No. 2 and cull grade potatoes and a decrease in No. 1 grade (columns 20, 21, 22),

The effect of place combined with that of culture is shown for 6 varieties in Tables 14 and 15. The stock was grown at different places for varying lengths of time and then brought to the irrigated plat at Morrill for comparison. Some

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esults secured in irrigated trial plats at Morrill (13), with seed potatoes of 10 varieties, produced in y land plats at Bushnell (5) and irrigated plats at Morrill (13) for different numbers of years

1919			1920			1921				1922									
Per acre yield		Per cent of total of Grade U. S. No. 1	Place where seed was grown in 1919	Per acre yield		Per cent of total of Grade U. S. No. 1	Place where seed was grown in		Per acre yield		Per cent of total of Grade U. S. No. 1	Relative tuber type Number basis	Place where seed was grown in			Per acre yield		Per cent of total yield of various grades			
Total	Grade U. S. No. 1			Total	Grade U. S. No. 1		1919	1920	Total	Grade U. S. No. 1			1919	1920	1921	Total	Grade U. S. No. 1	Grade U. S. No. 1	Grade U. S. No. 2	Culls	"Run Out" tubers of U. S. No. 1 Size*
Bu. (2)	*Bu.* (3)	*Percent* (4)	*Plat* (5)	*Bu.* (6)	*Bu.* (7)	*Percent* (8)	*Plat* (9)	(10)	*Bu.* (11)	(12)	*Percent* (13)	(14)	(15)	(16)	(17)	*Bu.* (18)	(19)	*Percent* (20)	*Percent* (21)	*Percent* (22)	*Percent* (23)
							(I) TRIUMPH VARIETY (EARLY TYPE)														
560.0	471.0	80.9	M	358.0	315.0	88.0	M	M	297.8	145.2	48.8	3	M	M	M	114.5	48.9	42.7	45.7	11.6	42.7
.....	.....	.....	B	410.0	404.2	98.6	B	M	356.0	232.1	65.2	2	B	M	M	132.9	103.0	77.5	16.7	5.8	14.8
.....	.....	.....	...	.....	.....	.....	B	B	344.2	278.6	80.9	8	B	B	M	145.6	114.9	78.9	14.8	6.3	17.1
.....	.....	.....	...	.....	.....	.....	...	...	.....	.....	.....	...	B	B	B	285.3	245.9	86.2	9.3	4.5	5.9
							(II) TRIUMPH VARIETY (VIGOROUS VINE TYPE)														
ity, Nebraska			K	.....	.....	.....	K	K	379.5	304.0	80.1	7	K	K	M	184.7	128.7	69.7	23.0	7.3	40.8
.....	.....	.....	...	.....	.....	.....	...	...	.....	.....	.....	...	K	K	B	339.2	241.9	71.3	12.5	16.2	6.6
							(III) IRISH COBBLER VARIETY (WISCONSIN LOT)														
473.0	346.0	73.2	M	377.0	345.7	91.7	M	M	399.6	192.3	48.1	2	M	M	M	215.2	132.8	61.7	21.5	16.8	61.7
.....	.....	.....	B	507.5	461.8	91.0	...	...	.....	.....	.....	...	...	...	...	.....	.....	.....	.....	.....	.....
.....	.....	.....	...	.....	.....	.....	B	B	509.2	341.7	67.1	6	B	B	M	296.2	251.5	84.9	10.8	4.3	5.8
.....	.....	.....	...	.....	.....	.....	...	...	.....	.....	.....	...	B	B	B	359.2	321.5	89.5	9.0	1.5	1.7
							(IV) IRISH COBBLER VARIETY (MINNESOTA LOT)														
.....	.....	.....	Mi	442.8	386.6	87.3	Mi	M	420.8	265.7	63.1	4	Mi	M	M	181.0	132.3	73.1	17.8	9.1	73.1
.....	.....	.....	...	.....	.....	.....	Mi	B	522.3	351.6	63.6	5	Mi	B	M	196.2	142.4	72.6	20.6	6.8	36.3
.....	.....	.....	...	.....	.....	.....	...	...	.....	.....	.....	...	Mi	B	B	397.3	342.4	86.2	8.9	4.9	9.3
							(V) EARLY OHIO VARIETY														
564.0	417.7	74.0	M	281.7	275.3	96.7	M	M	352.5	160.0	45.4	3	M	M	M	147.5	82.3	55.8	20.1	24.1	53.6
.....	.....	.....	...	.....	.....	.....	B	B	320.0	166.7	52.1	5	B	B	M	218.0	128.6	59.0	21.7	19.3	17.2
.....	.....	.....	...	.....	.....	.....	...	...	.....	.....	.....	...	B	B	B	294.0	219.9	76.8	19.2	4.0	2.0
							(VI) DOWNING VARIETY														
814.5	713.5	87.6	M	468.0	426.3	90.9	M	M	283.8	199.7	70.4	5	M	M	M	166.3	88.6	53.3	31.7	15.0	43.1
.....	.....	.....	B	467.6	440.2	94.1	B	M	435.6	331.7	76.1	6	B	M	M	179.3	91.1	50.8	30.8	18.4	42.0
.....	.....	.....	...	.....	.....	.....	B	B	457.2	349.7	76.5	7	B	B	M	223.8	135.4	60.5	27.9	11.6	21.0
.....	.....	.....	...	.....	.....	.....	...	...	.....	.....	.....	...	B	B	B	324.0	275.4	85.0	10.6	4.4	6.8
							(VII) PEARL VARIETY														
469.5	246.5	52.5	M	438.1	395.7	90.3	M	M	389.5	158.2	40.6	8	M	M	M	149.5	60.3	40.3	30.3	28.9	40.3
.....	.....	.....	B	689.2	528.3	76.6	...	...	.....	.....	.....	...	...	...	...	.....	.....	.....	.....	.....	.....
.....	.....	.....	...	.....	.....	.....	B	B	470.7	229.2	48.7	5	B	B	M	139.8	78.2	55.9	32.0	12.1	44.8
.....	.....	.....	...	.....	.....	.....	...	...	.....	.....	.....	...	B	B	B	383.7	316.6	82.5	13.6	13.7	8.9

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esults secured in irrigated trial plats at Morrill (13), with seed potatoes of 10 varie-
lry land plats at Bushnell (5) and the irrigated plats at Morrill (13) for different

	1920			1921					1922						
	Place where seed was grown in 1919	Per acre yield: Total	Per acre yield: Grade U. S. No. 1	Per cent of total of Grade U. S. No. 1	Place where seed was grown in: 1919	Place where seed was grown in: 1920	Per acre yield: Total	Per acre yield: Grade U. S. No. 1	Per cent of total of Grade U. S. No. 1	Relative tuber type Number basis	Place where seed was grown in: 1919	Place where seed was grown in: 1920	Place where seed was grown in: 1921	Per acre yield: Total	Per acre yield: Grade U. S. No. 1	Per cent of total yield of various grades: Grade U. S. No. 1	Per cent of total yield of various grades: Grade U. S. No. 2	Per cent of total yield of various grades: Culls	"Run Out" tubers of U. S. No. 1 Size*
	Plat (5)	Bu. (6)	Bu. (7)	Percent (8)	Plat (9)	Plat (10)	Bu. (11)	Bu. (12)	Percent (13)	(14)	Plat (15)	Plat (16)	Plat (17)	Bu. (18)	Bu. (19)	Percent (20)	Percent (21)	Percent (22)	Percent (23)
(VIII) RURAL NEW YORKER VARIETY																			
	M	426.8	390.8	93.8	M	M	280.6	249.0	87.3	6	M	M	M	100.2	40.6	40.5	26.6	32.9	11.6
	....	.....	.....	.....	B	B	401.5	369.3	92.0	8	B	B	M	187.8	116.1	61.8	29.6	8.6	19.8
	....	.....	.....	.....	.....	.....	.....	.....	.....	....	B	B	B	233.3	158.4	67.9	22.3	9.8	19.8*
(IX) RUSSET RURAL NEW YORKER VARIETY																			
	M	436.2	405.2	92.9	M	M	369.5	359.2	97.2	5	M	M	M	168.5	115.6	68.6	24.9	6.5	56.3
	B	530.5	496.0	93.5	B	M	470.8	446.2	94.8	5	.....	.....	.....	.....	.....	.....	.....	.....	.....
	....	.....	.....	.....	B	B	489.5	469.3	95.8	8	B	B	M	139.2	90.3	64.9	27.0	8.1	32.6
	....	.....	.....	.....	.....	.....	.....	.....	.....	....	B	B	B	156.5	128.2	81.9	15.1	3.0	19.3*
(X) GREEN MOUNTAIN VARIETY																			
	M	507.0	457.3	90.2	M	M	379.5	295.0	77.7	6	M	M	M	80.0	51.6	64.5	31.6	3.9	.....
	....	.....	.....	.....	B	B	469.5	325.5	88.1	7	B	B	M	120.3	83.1	69.1	27.1	3.8	.....
	....	.....	.....	.....	.....	.....	.....	.....	.....	....	B	B	B	145.0	90.2	62.2	28.5	9.3	.....
(XI) RUSSET BURBANK VARIETY																			
	M	310.3	255.5	82.3	M	M	252.0	133.3	52.9	5	M	M	M	127.5	55.0	43.1	44.8	12.1	.....
	....	.....	.....	.....	B	B	341.0	244.2	60.0	5	B	B	M	215.0	91.8	42.7	49.5	7.8	.....
	....	.....	.....	.....	.....	.....	.....	.....	.....	....	B	B	B	286.3	198.0	69.2	28.7	2.1	.....
(XII) KING VARIETY																			
	M	564.2	532.0	94.3	M	M	398.3	370.8	93.1	7	M	M	M	95.2	56.4	59.2	34.5	6.3	50.3
	B	566.3	546.8	96.5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	....	.....	.....	.....	B	B	409.2	380.8	93.1	8	B	B	M	103.5	65.0	62.8	33.5	3.7	51.1
	....	.....	.....	.....	.....	.....	.....	.....	.....	....	B	B	B	109.8	82.8	75.4	20.4	4.2	18.4*
MEAN OF 10 VARIETY LOTS (NOS. I, III, V, VI, VII, VIII, IX, X, XI, XII)																			
	M	417.0	379.9	91.1	M	M	335.3	226.3	67.5	4.2	M	M	M	136.4	73.2	53.0	31.2	15.8	44.9*†
	....	.....	.....	.....	B	B	411.2	315.5	76.7	6.7	B	B	M	177.2	113.8	64.1	27.5	8.4	29.4*†
	....	.....	.....	.....	.....	.....	.....	.....	.....	....	B	B	B	257.7	203.7	77.8	17.6	5.6	9.7*†

) Irrigated.
5) Dry land.
ıball County.

*Per cent of "run out" tubers in VIII, IX, and XII. Could not be determined as accurately as with other varieties; percentages may be too high.
†X and XI not averaged into final averages for "run out" tubers.

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—Place and culture as factors influencing value of seed potatoes. Ratio of yield, pro- in irrigated plat at Morrill (13), by seed potatoes from various plats to yield pro- by dry land seed grown in Bushnell plat (5). Original seed was the same for each For total yield from Bushnell stock see Table 13.

e where seed potatoes were grown each previous year			Varieties in trials						Average from six varieties	Average from three varieties (4)(5)(7)
.9	1920	1921	Triumph	Irish Cobbler	Downing	Pearl	Russet Rural New Yorker	King		
)	Plat and plat number (2)	(3)	Per cent (4)	Per cent (5)	Per cent (6)	Per cent (7)	Per cent (8)	Per cent (9)	Per cent (10)	Per cent (11)
			SEASON OF 1920							
(5)*....	.....	.....	100	100	100	100	100	100	100	100
(17)*...	.....	.....	71.6	89.0	.....	84.6	94.1	89.2	.....	81.7
(15)*...	.....	.....	76.8	90.5	84.1	76.1	94.2	85.3	83.4	81.1
21)*....	.....	.....	80.2	44.5	102.5	68.4	94.6	94.5	.....	.....
(3).....	.....	.....	87.3	74.3	100.1	63.6	82.2	99.6	84.5	75.1
(7).....	.....	.....	66.2	66.8	87.3	75.9	93.3	82.6	78.5	69.6
(8).....	.....	.....	65.3	63.7	.....	.....	86.2	71.5	.....	.....
(4).....	.....	.....	51.5	57.4	86.2	37.7	81.4	65.2	63.2	48.9
of two lots continuously on dry land (a) (b)			85.8	99.5	.....	92.3	97.1	94.6	.....	92.5
of four lots irrigated one year (e) (f) (g) (h)			67.6	65.5	.....	.....	85.8	79.7	.....	.....
			SEASON OF 1921							
(5)*....	Bushnell (5)*....	.....	100	100	100	100	100	100	100	100
(17)*...	Chadron (17)*...	.....	89.3	99.5	96.6	90.3	90.9	114.2	96.8	93.0
21)*....	Angora (21)*....	.....	93.9	15.5	65.8	37.6	67.1	53.4	55.5	49.0
(5)*....	Morrill (13).....	.....	103.4	.....	95.3	.....	96.2	.....	.....	.....
(17)*...	Morrill (13).....	.....	110.0	90.2	.....	93.5	.....	.....	.....	97.9
(15)*...	Morrill (13).....	.....	103.5	52.4	90.7	75.3	92.4	.....	.....	78.7
(3).....	Morrill (13).....	.....	86.5	79.8	62.1	72.1	75.5	97.3	78.9	79.5
(7).....	Bayard (7).....	.....	81.6	61.3	89.2	37.3	94.8	74.2	73.2	60.2
(8).....	Minatare (8).....	.....	87.3	91.2	86.4	57.3	81.1	64.0	77.9	78.6
(4).....	Kimball (4).....	.....	66.6	57.7	66.4	33.7	67.2	78.6	70.0	69.3
(7).....	Morrill (13).....	.....	93.2	89.7	89.1	57.3	.....	.....	.....	80.1
(8).....	Morrill (13).....	.....	92.4	.....	.....	.....	54.4	.....	.....	.....
(4).....	Morrill (13).....	.....	96.9	65.2	79.4	59.0	71.5	.....	.....	73.7
(5)*....	Kearney (2).....	.....	.....	.....	92.3	64.2	63.7	78.6	.....	.....

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DED.—*Place and culture as factors influencing value of seed potatoes. Ratio of d in irrigated plat at Morrill (13), by seed potatoes from various plats to yield dry land seed grown in Bushnell plat (5). Original seed was the same for each al yield from Bushnell stock see Table 13*

ed potatoes were grown each previous year		Varieties in trials						Average from six varieties	Average from three varieties (4)(5)(7)
1920	1921	Triumph	Irish Cobbler	Downing	Pearl	Russet Rural New Yorker	King		
and plat number (2)	(3)	*Per cent* (4)	*Per cent* (5)	*Per cent* (6)	*Per cent* (7)	*Per cent* (8)	*Per cent* (9)	*Per cent* (10)	*Per cent* (11)
		SEASON OF 1921							
on dry land for two successive		**94.7**	**99.7**	**98.3**	**95.7**	**95.5**	**107.1**	**98.5**	**96.7**
n dry land one year at Bushnell (5) irrigated one year Morrill (n) (o)		**106.7**							
irrigated two consecutive t)		**80.5**	**72.5**	**76.0**	**62.7**	**79.7**	**78.5**	**75.0**	**71.9**
irrigated one year at Morrill (13), tare (8) or Kimball (5) and one 3) (q) (u) (v) (w)		**92.2**							
		SEASON OF 1922							
Bushnell (5)*	Bushnell (5)*	**100**	**100**	100	100	100 †	100	100	100
Chadron (17)*	Chadron (17)*	69.7		71.8	64.7	171.5			
Angora (21)*	Angora (21)*	74.4		65.7	45.9	154.0			
Bushnell (5)*	Morrill (13)	45.1	82.4	69.1	36.4	84.0	89.1	67.7	57.9
Morrill (13)	Morrill (13)	43.1		55.3					
Morrill (13)	Morrill (13)	40.1	59.9	51.3	39.0	101.5	81.8	62.3	46.3
Bayard (7)	Bayard (7)	47.8	63.1	63.2	42.2	126.2	53.1	65.9	51.0
Miniatare (8)	Miniatare (8)	80.7	74.3		39.6	81.4	84.1		64.9
Kimball (4)	Kimball (4)	53.7	59.3	76.8	38.0	139.3			50.3
s on dry land for three consecutive		84.9		85.9	82.4	135.5			
ts irrigated for three consecutive) (kk)		55.0	64.2		39.7	112.1			53.1

on dry land the previous year or years.
orker on very high poorly irrigated part of field in 1922—results not representative.

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Place and culture as factors influencing quality of seed potatoes produced, when ing the market quality of the crop grown from seed potatoes that have been raised rious conditions. Seed stock of each variety from same original source in 1919. tive trials near Morrill with irrigation

seed potatoes were grown each year			Per cent of total crop produced, of U. S. No. 1 Grade quality							
			Varieties in trials						Average from 6 varieties	Average from 3 varieties (4) (5) (7)
	1920	1921	Triumph	Irish Cobbler	Downing	Pearl	Russet Rural New Yorker	King		
	(2)	(3)	*Per cent* (4)	*Per cent* (5)	*Per cent* (6)	*Per cent* (7)	*Per cent* (8)	*Per cent* (9)	*Per cent* (10)	*Per cent* (11)
			SEASON OF 1920							
...	.....	.....	98.6	91.0	94.1	76.6	93.5	96.5	91.7	88.7
...	.....	.....	93.7	94.2	.....	84.6	99.0	93.7	.....	90.8
..	.....	.....	95.4	90.0	93.1	83.9	99.3	98.0	93.3	89.7
..	.....	.....	84.0	87.2	88.2	62.3	94.4	96.1	85.4	77.8
..	.....	.....	88.0	91.7	90.9	90.3	92.9	94.3	91.4	90.0
..	.....	.....	90.3	80.4	85.6	63.9	100.0	92.9	85.5	78.2
..	.....	.....	94.4	89.0	.....	.....	97.1	95.7	.....	.....
..	.....	.....	87.1	74.1	94.1	85.0	94.4	98.0	88.8	82.1
ts on dry land one year (a) and (b)...			96.7	92.6	.....	80.6	96.3	95.1	.....	89.8
ts irrigated for one year (e) (f) (g) (h)..			89.9	83.8	.....	.....	96.1	95.2	.....	.....
			SEASON OF 1921							
...	Bushnell (5)*....	.....	84.5	67.1	76.4	48.7	95.9	93.0	77.6	66.8
...	Chadron (17)*...	.....	84.5	60.8	80.3	47.0	95.3	82.4	75.1	64.1
..	Angora (21)*....	.....	47.6	47.3	71.4	33.9	89.7	74.5	60.7	42.9
...	Morrill (13).....	.....	65.2	.....	76.1	.....	94.8	.....	.....	.....
...	Morrill (13).....	.....	63.6	57.2	.....	44.2	.....	.....	.....	55.0
..	Morrill (13).....	.....	76.0	59.1	76.4	45.4	92.6	.....	.....	60.2
..	Morrill (13).....	.....	48.8	48.2	70.4	46.9	97.2	93.3	67.5	48.0
..	Bayard (7)	.....	42.2	47.5	81.7	63.5	94.3	94.8	70.7	51.1
...	Minatare (8)....	.....	73.3	61.8	81.0	54.8	94.5	93.0	76.9	64.3

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5 CONCLUDED.—*Place and culture as factors influencing quality of seed potatoes produced, :n considering the market quality of the crop grown from seed potatoes that have been :ed under various conditions. Seed stock of each variety from same original source in 1919. nparative trials near Morrill with irrigation*

:e where seed potatoes were grown each year			Per cent of total crop produced, of U. S. No. 1 Grade quality							
			Varieties in trials						Average from 6 varieties	Average from 3 varieties (:) (5) (7)
1919	1920	1921	Triumph	Irish Cobbler	Downing	Pearl	Russet Rural New Yorker	King		
(1)	(2)	(3)	*Per cent* (4)	*Per cent* (5)	*Per cent* (6)	*Per cent* (7)	*Per cent* (8)	*Per cent* (9)	*Per cent* (10)	*Per cent* (11)
			SEASON OF 1921							
ll (4).....	Kimball (4).....	.....	55.9	49.4	71.0	66.8	93.8	92.3	71.5	57.4
d (7).....	Morrill (13).....	.....	43.8	40.2	65.2	51.8	.....	.....	.....	46.3
ll (4).....	Morrill (13).....	.....	51.5	45.0	80.1	40.5	96.0	.....	.....	45.7
ell (5)*....	Kearney (2).....	.....	73.6	.....	75.8	38.3	93.0	91.4	.....	.....
re of 2 lots on dry land for two consecutive s (k) (l).....			84.5	64.0	78.4	47.4	95.6	87.7	76.3	65.4
re of 2 lots on dry land one year and irrigated year (n) (o).....			64.4	.....	.....	.....	.....	.....	.....	.....
re of 4 lots irrigated for two years (q) (r) (s) (t)..			55.0	52.5	76.0	58.0	94.9	93.4	71.6	55.2
re of 2 lots irrigated two successive years but ferent points (u) (v).....			47.6	42.6	72.7	47.6	.....	.....	.....	45.9
			SEASON OF 1922							
ell (5)*....	Bushnell (5)*....	Bushnell (5)*....	86.2	89.5	85.0	82.5	81.9	75.4	83.4	86.1
on (17)*...	Chadron (17)*...	Chadron (17)*...	82.0	.....	85.9	70.3	86.5	70.9	.....	.....
a (21)*....	Angora (21)*....	Angora (21)*....	74.0	.....	63.8	40.6	69.7	.....	.....	.....
ell (5)*....	Bushnell (5)*....	Morrill (13).....	78.9	84.9	69.5	55.9	64.9	62.8	68.0	73.2
ell (5)*....	Morrill (13).....	Morrill (13).....	77.5	.....	50.8	.....	.....	.....	.....	.....
l (13).....	Morrill (13).....	Morrill (13).....	42.9	61.7	53.3	40.3	68.6	59.2	54.3	48.2
d (7).....	Bayard (7).....	Bayard (7).....	74.0	81.9	68.5	65.2	72.2	70.8	43.3	73.7
re (8)....	Miniatare (8)....	Miniatare (8)....	80.2	61.2	.....	65.7	81.9	72.3	.....	69.0
ll (4).....	Kimball (4).....	Kimball (4).....	82.3	80.3	79.5	65.5	90.5	.....	.....	79.4
ge of 2 lots continuously on dry land for three s (bb) (cc).....			74.1	.....	85.4	76.4	84.2	73.2	.....	.....
ge of 4 lots continuously irrigated for three s (gg) (hh) (ii) (jj).....			69.8	71.3	.....	59.2	78.8	.....	.....	67.6

es dry land plats. Numbers in parentheses are trial plat numbers.

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of the points at which the seed was produced were irrigated and others were not. The Morrill and Bayard plats were located on relatively flat land that could be irrigated readily. The irrigated Kimball plat never received sufficient water to produce a maximum crop, while proper irrigation of the Minatare plat was difficult because of light soil and rough topography.

The highest yields from the trials at Morrill were generally secured from the Bushnell dry land seed (Table 14). For this reason the total yield from this stock has been considered as 100 in the presentation of data. Yields from the other seed are given on the basis of per cent of yield compared with Bushnell stock. The yields from the Chadron stock were generally second to Bushnell, while all irrigated lots were considerably lower than these dry land lots. The reduced yields noted in Table 13 as the result of continued irrigation were consistently borne out by these trials.

The percentages of No. 1 tubers of the different lots discussed above are shown in Table 15. This is further evidence that irrigation of seed stocks affected the market quality of the tubers the following year.

The direct relationship of tuber type to yield is shown in Table 13, columns 11 and 14. Whenever the tuber type was low the yield was correspondingly light.

Deterioration in tuber type in irrigated stock is shown in the notes for tuber type as associated with yield for individual tuber units of several varieties when grown under irrigation and on dry land (Table 11).

The irrigated seed which produced lower yields and poor quality tubers also produced plants with distinctive degenerate symptoms. The fresh dry land seed seldom produced degenerate or run-out plants the first year under irrigation. A few of the plants from seed irrigated 1 year showed serious degeneration, while many others exhibited mild symptoms of degeneracy. Stock grown under irrigation 3 years generally produced only degenerate plants, most of them in the more advanced stages. Seed from the various irrigated plats gave relatively the same results.

TRANSMISSION OF DEGENERACY

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TABLE 16—*Units in various stages of degeneration, from most degenerate (13 and 37) to least degenerate (923). Kimball Pearl units, 1919. See table 7 for yield*

(Notes recorded July 28, 1919)

IRRIGATED PLAT NO. 4

Unit number	Number of hills planted	Per cent of plants in various plant vigor groups								Mean vigor of unit
		No plants 0	P— 14.3%	P 28.6%	M— 42.9%	M 57.2%	M+ 71.5%	G 85.8%	G+ 100%	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
13	88	35.0	55.0	8.0	2.0	0	0	0	0	12.6
37	196	48.5	49.5	1.5	1.0	0	0	0	0	8.0
19	164	20.0	29.0	35.0	14.0	2.0	0	0	0	20.2
369	288	12.0	6.0	6.0	10.0	22.0	20.0	16.0	6.0	54.5
483	276	0	2.0	5.0	20.0	30.0	17.0	15.0	11.0	63.5
500	303	2.0	2.0	8.0	22.0	28.0	22.0	14.0	2.0	59.1
923	340	0	3.0	1.0	13.1	11.0	15.0	37.0	20.0	75.1

*Per cent numbers in heading refer to numerical value arbitrarily given to each vigor group. See p. 29.

an affected tuber becomes progressively weaker, until eventually nothing but low yielding inferior plants and tubers are produced. (Table 16.) Many tubers in such cases become so degenerate that they will not produce plants, thus accounting for many missing hills in some fields. As degeneracy progresses, the symptoms become more pronounced in both tops and tubers, and the yield is reduced (Table 13 and figs. 19, 20, and 21). This transmission applies to tuber type, vigor, type of plant growth, and yield. Low yielding units were not brought back to a normal condition by tuber line selection or by growing them in a possibly more favorable environment.

Direct tuber transmission as just outlined can not account for the amount and rate of spread of degeneracy occurring in some lots. All high yielding tuber units from the Pearls and irrigated Triumphs eventually degenerated. In other cases, when degenerate and vigorous units were grown in close proximity to each other, the degeneration noticed later in the progeny from the vigorous units can be explained only by the assumption that this degeneracy is communicated from one plant to another in the field.

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Conclusive proof of field transmission was not secured by means of controlled experiments prior to 1922. However, the earlier data yield many facts which are very suggestive. *

A careful study of the field notes and data concerning the tuber units planted in 1917 and 1918 in Kimball and Scotts Bluff Counties (Table 8) has been made. Frequently when the progeny of good, vigorous hills produced plants ranging from good to poor, it was discovered that during the previous season the good unit was growing adjacent in the row to a poor degenerate unit (Table 8, units 173, 254, 278, 291, 358, and 366). The high percentage of degenerate plants in the Triumph field at Minatare in 1917 resulted in the distribution of poor plants thruout the entire field, so that practically all units degenerated in 1918. This is very suggestive that transmission took place during the growing season.

The planting plan of the 1919 Kimball plat is given as Table 17. The adjacence of lot 923 (line e) to the very poor lots 13 and 19 in the next row very probably permitted of field transmission and may explain the rapid decrease in the quality of lot 923 (Table 7).

Further suggestive evidence on this point can be secured from figure 15. Some of the Triumph units at Bayard produced very vigorous vines but very poor tubers. It is quite possible that infection took place during the growing season and that the plant was not noticeably affected but that such infection was sufficient to influence the shape of the tubers. The following year (1921) all selected units (marked in fig. 15) produced degenerate plants and tubers.

In order to determine the extent of field transmission, some badly run-out tubers from 2 degenerating unit strains (560 and 580) of Triumphs were planted alternately in the row with good vigorous seed stock (T13) secured from a very good field in Kimball County. These plantings were made at the Scotts Bluff Experiment Farm on both irrigated and dry land in 1921. The seed used was the same in each plat, one-half of each tuber being planted in each plat. The data

*During the winter of 1923, 11 tuber grafts were made with normal and run out tubers. These grafts with proper checks were planted in the greenhouse. The progeny harvested in April and May was planted at the Scotts Bluff Experi-

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TABLE 17—*Relative position in field of unit lines and per cent of disease content*
Pearl potatoes—Kimball, Plat 4, 1919.

(a)	General field planting — (Triumph)					
(b)	14.2	(46.0%)		14.1	(41.6%)	
(c)	14.4	(38.0%)		14.3	(46.8%)	
(d)	Check grown on farm since 1910					
(e)	923	(3.6%)	(From dry land spring 1919)			
(f)	13	(100%)		19	(77.8%)	
(g)	20	(46.2%)				
(h)	483	(49.4%)				
(i)	483	(49.4%)				
(j)	369	(37.6%)				
(k)	369	(37.6%)				
(l)	500	(28.1%)				
(m)	500	(28.1%)				
(n)	Commercial	37	(100%)			
(o)	General field	(Pearl)				

in Table 18 show that the yield from the degenerated strains was very much less in 1921 than from the new healthy stock (T13). The close proximity of the run-out stock did not seem to have an adverse influence upon the yield of tubers in 1921. The healthy stock planted alternately with the most degenerate lot (560) actually yielded more than the same healthy stock planted elsewhere by itself (lines f, h, i, j, Table 18). (This may have been due to the lack of competition on the part of the run-out plants). However, the proximity apparently had some influence upon the tuber type, for these same good lots adjacent to these same run-out lots showed some deterioration in tuber type in 1921. (Table

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Table 2. Effect of proximity of degenerate strains of potatoes upon normal vigorous lots when grown on dry land and on irrigated land. Scotts Bluff Experiment Farm, 1921 and 1922

Lot No.	Culture of seed: Prior to 1921	Culture of seed: Season of 1921	1921 results. Plants of both lots alternated: Yield per acre, U.S. No. 1 grade	1921 results. Plants of both lots alternated: Yield per acre, Total yield	1921 results. Plants of both lots alternated: Tuber type	1922 results in irrigation plat (11) Plants of each lot in separate plat: Yield per acre, U.S. No. 1 grade	1922 results in irrigation plat (11) Plants of each lot in separate plat: Yield per acre, Total yield	1922 results in irrigation plat (11) Plants of each lot in separate plat: Tuber type
			Bushels	*Bushels*		*Bushels*	*Bushels*	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(a)	560	Irrigation	80.0	103.3	P	108.3	139.2	P to M+
(b)	T18	Irrigation	193.3	206.6	G	118.6	149.3	P to G
(c)	560	Dry land	25.0	42.6	M	143.3	183.9	P to G
(d)	T18	Dry land	26.6	51.2	G—	158.3	183.3	M to G
(e)	560	Irrigation	25.0	58.3	M to P	81.0	98.5	M to P
(f)	T18	Irrigation	265.0	293.3	M to P	116.9	140.1	M to P
(g)	560	Dry land	5.3	17.3	P	112.0	143.3	P
(h)	T18	Dry land	20.0	66.6	M+	131.3	152.5	M—
(i)	Check	Dry land	229.1	250.0	G	.....	.....	.....
(j)	Check	Dry land	40.6	76.6	G	210.6	252.7	G+
(k)	Check	Dry land	Original field in 1921		.....	.....	263.2	G+
(l)	Mean of yield from potatoes produced in 1921 by		T18 lots alternating with 560		.....	136.0	166.3	P to G
(m)			T18 lots alternating with 560		.....	124.1	146.3	M— to P
(n)			T18 lots on dry land		.....	142.3	167.9	.....
(o)			T18 lots on irrigated land		.....	117.8	144.7	.....
(p)			All T18 lots		.....	130.1	156.3	.....
(q)			All 560 and 560 lots		.....	111.2	141.2	.....

Check lots from same field in 1920 as T18 lots; i. e., isolated field. P, poor; M, medium; G, good.

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In 1922 the total yield from the normal vigorous stock was only a trifle greater than from the degenerate stocks (Table 18, column 8). There was a greater difference in the yield of grade No. 1 stock. The tuber type was only slightly better (column 9). Evidently proximity had some effect in hastening degeneracy, as the check lots (line j) which had been grown in a separate part of the same dry land plat and the new stock from the original field (line k) both outyielded the formerly normal stock (T13) by a margin of approximately 100 bushels per acre.

There was some difference in the relationship of the 2 degenerate strains to the normal strain, as the T13 lots adjoining the 580 lots (Table 18, line (1)) did not deteriorate as much in yield or type as those adjacent to the more inferior 560 lots.

FIG. 22.—Tubers produced by normal and run-out tubers when plants were alternated in same row. First and third from left, from normal tuber. Note extreme elongation and small size of "run-out" stock, also somewhat elongated shape of tubers from healthy tubers, indicating transmission of degeneracy. Scotts Bluff (11), 1921. (See Table 18.) For plant characteristics see figure 20 A and D.

The 1922 yield from all strains produced on dry land in 1921 was considerably greater than from the lots produced on irrigated land. (Possible reasons for this are discussed later.) The yields from these dry land lots, however, averaged almost 100 bushels per acre less than the check lots, from isolated seed plats (n), (j), (k).

It will be noted that all T13 lots in 1922 gave a yield of 156.3 bushels (line p) and all 580 and 560 lots (line g) a yield of 141.2 bushels. The 252.7 bushel yield in 1922 of the check lots (line j, column 8) is approximately 100 bushels greater than that of the same stock grown in proximity the previous year to the degenerate strains (line p). Thus there was a decrease of 41.7 per cent in yield of T13, which can be attributed only to being grown adjacent to degenerate plants the previous year.

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The check lot (line j, column 8) was not materially affected in 1921, as shown by the fact that it yielded practically as well as fresh stock grown in the original field in 1921 (line k, column 8).

A study of the field history of some of the lots in the Morrill plats (Tables 13, 14, and 15) shows that almost invariably when a lot degenerated to an unusually great extent in any one season it had been in an adjacent row to a very degenerate lot the previous year. It has been noted from extensive observations in connection with the seed potato certification work that in regions where potato fields are scarce and commercial potato culture relatively new, there is less of this type of degeneracy than in regions where potato growing is more intensively developed.

It has been shown in general that fresh dry land seed shows less degeneracy than seed from the same original source but grown under irrigation. This superiority of dry land seed may be due largely to the elimination of the weak strains by the adverse conditions for growth under such culture. On the other hand, the favorable growing conditions afforded by irrigation undoubtedly allow sufficient development of tubers on degenerate plants, so that they are in many instances saved for seed. Another possible explanation of why irrigated conditions are more conducive to the development of degeneracy may be that the rapid, vigorous growth of the plants actually makes them more susceptible. No carefully controlled checks have been run, to date, to determine to what extent insects may act as carriers of this degeneracy. It has been shown, however, that spindling tuber-like mosaic is transmitted from one plant to another by plant lice (Schultz and Folsom, 1923; Folsom, 1923). Since plant lice are very scarce in western Nebraska, they therefore can be only a minor factor in the transmission of this trouble.

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crop potatoes are used as seed to some extent in all parts of the South, but the total amount so used is small compared with the annual demands for northern stock (Stuart, 1922). Growing seed potatoes under a mulch is a practice which is limited largely to farm production for home use in the Corn-Belt states. The high altitude of western Nebraska makes the growing conditions in that region comparable to those of the more northern states, so far as length of growing season and mean soil temperature are concerned.

Vigorous seed from western Nebraska has given satisfactory yields when compared with seed stock from other sources. A critical examination, however, of the condition of western Nebraska potatoes has revealed the fact that some lots are uniformly vigorous, some uniformly unproductive, and others contain both weak and strong strains. It is evident from the foregoing experiments that the lack of vigor in some lots from this region is due largely to the presence of the spindling tuber type of degeneracy described

TABLE 19—*Effect of tuber type on vigor and yield. Seed tubers selected from degeneration seed stock of eight tuber lines of Pearl potatoes. Kimball, 1920*

	Unit number	Type of tubers planted						Decrease due to poor type seed tubers	
		Medium good type			Poor type				
		Number of hills	Vigor	Total yield per acre	Number of hills	Vigor	Total yield per acre	Vigor	Total yield per acre
	(1)	(2)	*Per cent* (3)	*Bushels* (4)	(5)	*Per cent* (6)	*Bushels* (7)	*Per cent* (8)	*Bushels* (9)
(a)	14.1	80	44.8	85.3	100	25.4	40.3	19.4	45.0
(b)	14.3	40	35.0	72.4	35	20.0	48.4	15.0	24.0
(c)	14.4	100	23.0	56.0	100	15.0	24.2	8.0	31.8
(d)	20.0	80	60.0	118.2	100	45.0	87.5	15.0	30.7
(e)	369.0	100	58.7	114.6	100	57.4	106.7	1.3	7.9
(f)	483.0	100	71.5	105.8	100	37.6	71.6	33.9	34.2
(g)	500.0	100	65.0	124.2	100	57.2	96.3	7.8	27.9
(h)	923.0	80	47.5	95.6	80	49.5	84.0	+ 2.0	11.6

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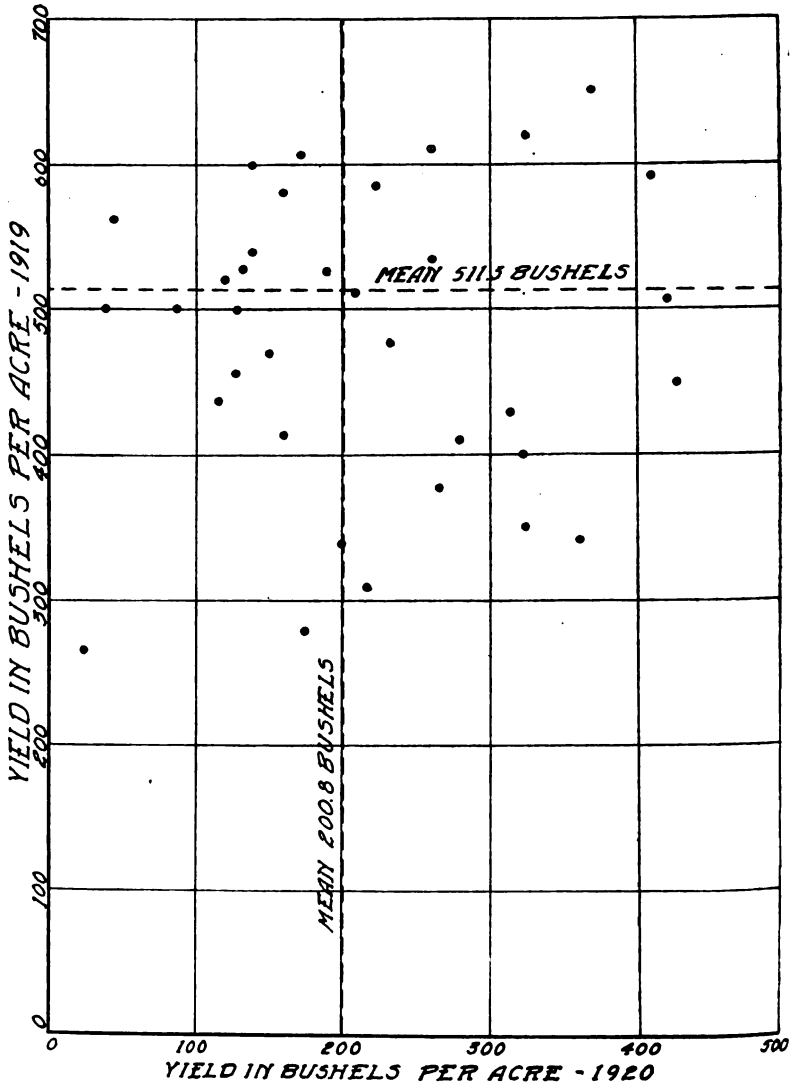

FIG. 23.—Relation of yield per hill in 1919 to yield of 20 progeny hills in 1920. (Triumph potatoes at Bayard (6).) Each dot represents one 4-hill unit. When degenerate plants were present in a field, there was no correlation between the yield of a unit strain from one year to the next. Hill selection is futile when a field of potatoes is in a degenerating condition.

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(page 24). The elimination or the control of this degeneracy is therefore one of the limiting factors in the production of good seed in western Nebraska.

It has been shown that this type of degeneracy (spindling tuber) affects the shape and other characteristics of the tuber. When this trouble is present the selection of the best type tubers will result in some slight improvement but at best it is only a makeshift method (as shown by Table 19). Many tubers may carry the condition without showing the symptoms distinctly and the trouble will still continue to increase to a serious extent. Hill selection is of but little value when degenerate plants are present, especially if they constitute more than about 5 per cent of the plants. This was clearly shown in a number of the experiments and is quite clearly brought out in figure 23. The high yield of the selected hills of 1919 was no guarantee that the 1920 yield would be high, for the field contained many degenerate plants which served as sources of infection. When degenerate plants are not present in a field, hill selection is of value to isolate early or late strains or possibly to isolate strains with regard to other characters.

The most practical field method of control is to secure foundation stock from a vigorous strain of seed that contains very little or no "run-out" stock, as determined by field and bin inspection. This stock should be planted in an isolated field plat (isolated by about 300 feet or more from any other potato field), on land that has not grown a crop of potatoes for at least two or three years, to guard against other diseases and against occasional volunteer plants. This seed plat should be kept free from weeds, since some weeds may possibly be hosts for this trouble, as has been found to be the case for mosaic. This seed plat should be inspected frequently, at which times all plants showing symptoms of this or any other trouble or disease should be removed. If tubers have already "set" on any such plants they should also be removed. The potatoes grown in this plat should be used for the main planting the following year.

A more careful method that will more certainly yield distinctly improved seed stock is the "tuber index" method (Perry, 1922). The tubers selected are indexed with a num-

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further selection and roguing take place. As this method requires a greenhouse, it is unavailable to practical growers. However, any grower can grow the stock in the seed plat by the hill unit method. This will enable him to rogue out undesirable stock more thoroly than when mass selection is followed.

From the standpoint of improving the quality of a large quantity of seed grown in a number of counties, this Station is resorting to the practice of growing a small quantity of potatoes from a hundred or more growers, in comparative trial plats. One of these is located in a Southern State (Louisiana), where readings can be made before the northern planting season; another is located in western Nebraska on dry land, where early and late plantings are made; and still another is made in the western irrigated district (Scotts Bluff County). By this means it is possible to advise growers at an early date concerning the quality of their seed stock. Also it enables one person to inspect a large number of lots of potatoes under identical growing conditions. Sometimes facts concerning lots are revealed in these trial plats which are not as apparent in the grower's own field. This applies to the control of mosaic and similar diseases as well as to spindle tuber.

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A Study of the Environmental Conditions Influencing the Development of Stem Rust in the Absence of an Alternate Host

II. INFECTION STUDIES WITH PUCCINIA GRAMINIS TRITICI FORM III AND FORM IX

GEORGE L. PELTIER

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SUMMARY

1. A detailed study of 2 biologic forms of *Puccinia graminis tritici* was undertaken to determine whether or not their reaction on the differential hosts remained consistent under various environmental factors. At the same time the influence of environmental factors on the growth of the differential hosts and on the development of the disease was determined.

2. The environmental factors controlled in this investigation were soil temperature, soil moisture, and air temperature. A relative humidity of between 95 and 100 per cent was maintained in all experiments. Both the intensity and duration of sunlight varied from day to day, but the total hours of sunshine was recorded for each experiment.

3. In no instance was the general type of infection of a biologic form on a differential host changed (1) by any of the environmental factors to which the differential host and biologic form were submitted, (2) by the source of the inoculum, or (3) by the source of seed of the differential hosts.

4. In the main the types of infection obtained with the 2 biologic forms on the differential hosts checked with those worked out by Stakman and Levine. A heterogeneous type of infection was obtained on 3 Durum varieties instead of a type reported by Stakman and Levine.

5. The best development of the differential hosts at the seedling, stooling, jointing, and heading stages occurred at 15° and 20° C. Temperatures of 10° and below resulted in a slow growth, while temperatures of 25° and 30° inhibited the growth of the plants.

6. The optimum temperature for initial infection with Form III is about 25° C., while with Form IX it is nearer 20°. The temperature range suitable for initial infection with Form IX is about 5° lower than with Form III.

7. The optimum temperature for the development of the disease with both forms on plants in the seedling, stooling and jointing stages was between 20° and 25° C. No infection

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8. The temperatures at which the plants make their best growth are generally the same as those at which the best development of the disease takes place.

9. The period of incubation of Form IX has been extended over a long length of time (7-9 weeks) by submitting inoculated plants to a low temperature. The length of this period depends not only on the temperature, but also on the stage of development of the organism in the leaf tissues of the host.

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A Study of the Environmental Conditions Influencing the Development of Stem Rust in the Absence of an Alternate Host

II. INFECTION STUDIES WITH PUCCINIA GRAMINIS TRITICI FORM III AND FORM IX

GEORGE L. PELTIER

INTRODUCTION

Stakman and Levine[1] have shown that *Puccinia graminis tritici* (Pers.) Erikss. and Henn. consists of a number of biologic forms, which can be determined by their action on different varieties of *Triticum* species. To date 37 such biologic forms have been identified by them thru the parasitic action on 12 differential hosts chosen from a large number of varieties of *Triticum* species.

To determine whether these biologic forms remain constant in their behavior under various environmental conditions, a detailed study of the host-parasite relation was undertaken with 2 of these forms, following as closely as possible the methods worked out by Stakman and Levine. At the same time an opportunity was afforded to determine the influence of environmental factors on the growth of the host plants and on infection and development of the disease.

The various soil and air temperatures employed were held constant in all instances. The same soil moisture was maintained in all experiments where it was controlled. In all experiments the relative humidity was maintained between 95 and 100 per cent. Sunlight varied from day to day, but the total hours of sunshine was recorded for each experiment.

EXPERIMENTAL METHODS

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the light factor still remains to be solved. It can be stated, however, that thru the use of refrigeration and automatically controlled electric heating units a series of temperatures from 5° to 30° C. were readily obtained. The principle involved was the cooling of a large room in the greenhouse. In this room were placed the cases in which the plants were grown. The heating units in the cases were then regulated to the temperature desired.

The plants were grown in galvanized cans 8x14 inches. The soil used in all the experiments was a sod soil taken from the Station Farm and composted near the greenhouses. Enough soil was obtained at one time for the entire season's work. When the cans were filled, the soil was sifted and mixed at the rate of 3 parts of soil to 2 parts of clean river sand. Ten kilograms of soil were used in each can with 500 grams of sand on top to serve as a mulch. All seeds were planted to a depth of 1½ to 2 inches.

When different soil and air temperatures were desired, modified Wisconsin soil-temperature tanks and glass tops of the same dimensions as the tanks were employed (Pl. 1). The modified Wisconsin soil-temperature tanks are in principle essentially like those described by Jones[1] and Johnson and Hartman[2]. The glass tops were made of wood frames and 2 panes of glass, thus giving a dead air space. By means of a thick layer of felt nailed to the bottom of the glass tops a very snug union was made between them and the tanks. For the control of the soil temperature a heating bulb was submerged in the water of the tank and the temperature of the water regulated with a mercury thermostat. The air temperature was controlled by electric heaters set along the side of the glass top and regulated by a thermostat placed in the center of the glass top. The cans were then placed in the holes of the lid.

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except to state that barring the misfortune of losing the plants on several occasions, the cases gave very satisfactory results.

The incubation chambers as already described[1] were modified Wisconsin soil-temperature tanks with a false bottom of slats and a tightly fitting cover of glass sash. Constant temperatures were obtained thru the use of a heating bulb controlled by a mercury thermostat.

Records of both soil and air temperatures were taken 3 times a day, the soil temperature at a depth of 3 inches and the air temperature from a thermometer hung just above the thermostat. The range of variation of the temperature in the cases was never more than one degree either way during the course of an experiment.

The method described in some detail by Goss [2] was used in determining and maintaining soil moisture. In the experiments reported on here, the soil moisture is expressed as the per cent of the moisture holding capacity rather than as per cent of dry weight. The same soil moisture, 68.2 per cent of the moisture holding capacity (23.8 per cent dry weight), was used in all experiments in the temperature cases, so that this factor remained as nearly constant as it was possible to maintain it.

Relative humidity was recorded with a Mitthof hair hygrometer. All readings were made with the doors of the cases closed, as extreme variations were recorded if an attempt was made to read these hygrometers at close range with the doors of the cases open. For the purpose of our study, the humidity, while rather high and not satisfactory to the best development of the host, was favorable for the maximum development of rust. Unless otherwise noted, the relative humidity maintained in the cases was 95 per cent or higher.

Sunlight was the most variable factor dealt with during the course of this investigation in that both the intensity and the duration of sunshine varied from day to day. During the winter months when the daily duration of sunshine was short, little or no rust developed. The total hours of sunshine prevailing during the course of all experiments were recorded.

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[1] Peltier, G. L.—A Study of the Environmental Conditions Influencing the Development of Stem Rust in the Absence of an Alternate Host. I. The Viability of the Uredinio-spores of *Puccinia graminis tritici* Form III. Neb. Agr. Exp. Sta. Res. Bul. 22; 16 p., fig. 3, 1922.

[2] Goss, R. W.—Relation of Environment and Other Factors to Potato Wilt Caused by *Fusarium oxysporum*. Neb. Agr. Exp. Sta. Res. Bul. 23; 84 p., fig. 5, 1922.

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It is hoped that within another year this difficulty will be solved thru the use of artificial lighting, so that this factor can be kept under control.

SOURCES OF MATERIAL

Inoculum of the biologic forms was kindly supplied by Dr. E. C. Stakman and Mr. M. N. Levine of the Minnesota Agricultural Experiment Station. During the season of 1921-1922, Form III was used. This form was described by Levine and Stakman[1]. Kanred, resistant to many of the other biologic forms, is very susceptible to this form, while Arnautka, Mindum, Speltz Marz, Kubanka, and Emmer are resistant.

Form IX, described by Stakman and Levine,[2] was used during the season of 1922-1923. To this form Kanred is resistant, while Arnautka, Mindum, Speltz Marz, Kubanka, and Emmer are susceptible.

These forms were chosen because of their behavior on the varieties mentioned above. In one case then Kanred was susceptible and the others resistant, and in the second case Kanred was resistant while the other varieties were susceptible.

TABLE 1.—*List of differential hosts used in the study of the biologic Forms III and IX*

Triticum compactum
Little Club, C. I. No. 4066
Triticum vulgare
Marquis, C. I. Nos. 3641 and 3276
Kanred, C. I. No. 5146
Turkey Red, C. I. Nos. 1558 and 1571
Kota, C. I. Nos. 6248 and 5878
Tricticum durum
Arnautka, C. I. Nos. 1493, 1494, 4064, and 4072
Mindum, C. I. No. 5296
Speltz Marz (Arnautka), C. I. No. 6236
Kubanka, C. I. Nos. 1440, 2094, 4063, and 6519
Acme, C. I. No. 5284
Triticum monococcum
Einkorn, C. I. No. 2433
Triticum dicoccum
White Spring Emmer (Vernal), C. I. No. 3686
Khapli, C. I. No. 4013

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one variety were used at one time or another in the experiments. The various varieties with the Cereal Investigations accession numbers are listed in Table 1. Owing to the fact that Turkey Red is so widely grown in Nebraska, it was included in the investigation along with the other differential hosts.

INOCULATION TECHNIC

For routine inoculation of stock plants and seedling experiments, the methods already described [1] were employed. The standard time for the incubation of the inoculated material was 48 hours.

Two methods of inoculating the plants grown in the cases were used. At the beginning of the work, definite amounts of spore suspensions were sprayed on the plants. However, the results were not always uniform, so the following method was resorted to. A definite amount of dry urediniospores was placed on a sheet of paper, and after the plants in the cases were well sprayed with water a sudden puff was given the spores on the paper, so that they settled down on the plants in a uniform fashion. This method of inoculation corresponded to as near natural infection as could be devised.

During the course of the season only one biologic form was used, so that there was no danger from mixing the forms of rust. Further, the experiments were started late in the fall and closed in the spring to lessen the danger of outside contamination by wind-borne urediniospores.

EXPLANATION OF THE SYMBOLS USED IN THE TABLES

For the sake of clearness, uniformity, and ease of comparison, the number of plants infected is expressed in percentage of plants inoculated.

In working out a set of symbols to express the degrees of infection the numerals 1 to 5 were employed, for the reason that these can be remembered more easily than any other type of symbol. In all instances the range of infection is given rather than the mean. The writer used these symbols

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Table 2 are listed both the degrees and the types of infection as adapted for our use from Stakman and Levine.[1] In recording the type of infection the writer may have stressed the size of the uredinia more than the other differences which appeared. It is suggested that a careful study of Table 2 and the plates be made to have the degrees and types of infection well in mind before the other tables are reviewed.

TABLE 2.—*Explanation of the symbols used to indicate degrees and types of infection in the tables*

DEGREES OF INFECTION

1.–TRACE
Uredinia very few in number (5 or less) and covering a limited surface.
2.–SLIGHT
Uredinia few in number (5 to 10).
3.–MODERATE
Uredinia moderate in number (10 to 25).
4.–CONSIDERABLE
Uredinia fairly numerous and scattered (25 to 50).
5.—ABUNDANT
Uredinia very many (50 or more), covering a large area of the affected host.

TYPES OF INFECTION

0.–IMMUNE
No uredinia developed; hypersensitive flecks usually present, but sometimes there is apparent absolutely no trace of mycelial invasion in the host tissues (Pl. 5, A).
1.–VERY RESISTANT
Uredinia minute and isolated; surrounded by sharp, continuous, hypersensitive, necrotic areas (Pl. 8, A).
2.–MODERATELY RESISTANT
Uredinia isolated, and small to medium in size; hypersensitive areas present in the form of necrotic halos or circles; pustules often in green, but slightly chlorotic islands.
3.–MODERATELY SUSCEPTIBLE
Uredinia medium in size; coalescence infrequent; development of rust somewhat subnormal; true hypersensitiveness absent; chlorotic areas, however, may be present (Pl. 5, C).
4.–VERY SUSCEPTIBLE
Uredinia large and coalescence frequent; true hypersensitiveness entirely absent, but chlorosis may be present when cultural conditions are unfavorable (Pl. 2, B).
X.–HETEROGENEOUS
Uredinia very variable, apparently including all types and degrees of infection on the same blade; no mechanical separation possible; on reinoculation small uredinia may produce large ones, and *vice versa*. Infection ill defined (Pl. 5, B).

MISCELLANEOUS SYMBOLS

(:)–Hypersensitive flecks.
(.)–Necrotic lesions.

In Tables 3 to 6 a slight departure from the above symbols was made. In recording the development of rust, the letter "F" was used to denote flecking, which normally precedes the appearance of pustules, while the letter "P" was employed to designate unruptured or rupturing uredina.

[1] Loc. cit.

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EXPERIMENTAL DATA

INFLUENCE OF INCUBATION TEMPERATURE ON INFECTION OF WHEAT SEEDLINGS BY PUCCINIA GRAMINIS TRITICI FORM III

Experiment 1.—On February 24, 1922, 120 seedling plants, 7 days old, of each variety of wheat listed in Table 3 were inoculated by hand and 30 of them were placed in each of the incubation chambers. These were maintained at the temperatures of 15°, 20°, 25°, and 30° C. After a period of 48 hours incubation, they were trimmed to one leaf and

TABLE 3.—*Influence of incubation temperature on infection of wheat seedlings by Puccinia graminis tritici Form III*

Experiment 1

Variety	Days after inoculation	Per cent of plants infected at				Degrees of infection at				Types of infection at			
		15°C.	20°C.	25°C.	30°C.	15°C.	20°C.	25°C.	30°C.	15°C.	20°C.	25°C.	30°C.
Little Club C. I. No. 4066	6	*	83	100	*	1	1–3	1–5	1–2	F	F	P	F
	8	43	90	100	50	1–3	1–4	3–5	1–2	P	P	P	P
	10	50	97	100	59	1–3	1–4	3–5	1–2	3–4	3–4	3–4	3–4
	14	50	97	100	59	1–3	1–4	3–5	1–2	4	4	4	4
Marquis C. I. No. 3641	6	0	*	100	*	...	1	2–5	1	...	F	P	F
	8	7	40	100	48	1–2	1–3	2–5	1–3	P	P	P	P
	10	13	40	100	52	1–2	1–3	2–5	1–3	3–4	3–4	3–4	3–4
	14	13	40	100	55	1–2	1–3	2–5	1–3	4	4	4	4
Kanred C. I. No. 5146	6	*	100	100	*	1	3–4	5	1–2	F	F	P	F
	8	40	100	100	26	1–3	4	5	1–2	P	P	P	F–P
	10	68	100	100	26	1–3	4	5	1–2	3–4	3–4	3–4	3–4
	14	68	100	100	29	1–3	4	5	1–2	3–4	4	4	4
Turkey Red C. I. No. 1558	6	0	*	80	0	...	1	1–5	...	...	F	P	...
	8	7	27	89	4	1	1–2	1–5	1	P	P	P	P
	10	7	27	89	4	1	1–2	1–5	1	4	3–4	3–4	3–4
	14	11	27	89	4	1	1–2	1–5	1	4	4	4	4
Kota C. I. No. 6248	6	17	97	100	52	1–3	1–3	1–4	1–2	F	F	F	F
	8	76	97	100	63	1–3	1–4	3–4	1–2	P	P	P	P
	10	83	97	100	63	1–3	1–4	3–4	1–2	3–4	3–4	3–4	3–4
	14	83	97	100	67	1–3	1–4	3–4	1–2	4	4	4	3–4
Kubanka C. I. No. 1440	6	*	87	96	0	1	1–4	1–4	...	F	F	P	...
	8	57	87	96	25	1–3	1–4	1–5	1	P	P	P	P
	10	78	100	96	25	1–3	1–4	1–5	1	X	X	X	X
	14	78	100	96	25	1–3	1–4	1–5	1	X	X	X	X
Einkorn	6	*	100	100	*	1	2–4	5	1	F	F	F	F
	8	80	100	100	71	1–4	2–4	5	1	P	P	P	P
	10	80	100	100	86	1–4	2–4	5	1–2	3–4	3–4	3–4	3
	14	80	100	100	86	1–4	2–4	5	1–2	3–4	4	4	4
Khapli C. I. No. 4013	6	43	100	100	*	1–3	1–4	3–5	1–2	F	F	F	F
	8	100	100	100	61	1–3	2–4	5	1–2	P	P	P	F
	10	100	100	100	72	1–3	2–4	5	1–2	P	P	1	1
	14	100	100	100	72	1–3	2–4	5	1–2	1	1	1	1

*Exact percentage of plants infected could not be determined, owing to indistinct flecking. For explanation of symbols used in this table see page 9.

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set on a bench in the greenhouse, the mean temperature of which, for the period of February 27 to March 10, was 27.5°. The total hours of sunshine for the period of the experiment was 105.9, a daily mean of 7.6 hours.

During incubation an even film of water occurred on the leaves of the plants held at 25° and 30° C., while only drops of water were noted on the plants kept at 15° and 20°. A summary of the results is listed in Table 3.

Of the plants incubated for 48 hours at 15° C., no flecks were found on Marquis and Turkey Red 6 days after inoculation. A trace of indistinct flecking appeared on Little Club, Kanred, Kubanka, and Einkorn, while from a trace to a moderate amount of flecks occurred on Kota and Khapli. Two days later, unruptured and ruptured uredinia were present on all varieties, the only difference being in the number of plants infected and the number of uredinia present. Ten days after inoculation the type of infection could be determined with safety. However, a final reading was made 14 days after inoculation.

The influence of a temperature of 15° C. on incubation for 48 hours was very noticeable on the reaction of the different varieties to rust. Both Marquis and Turkey Red showed but a trace to a light infection on only a small number of plants. At least 50 per cent or more of the plants of the other varieties were infected with varying amounts of rust. Khapli, the most resistant variety, as judged from the size of the uredinia, was the only one which became 100 per cent infected. In other words, while Khapli is extremely resistant to the development of rust, it is very easily infected. If we list the varieties in order of the ease of infection by rust at this incubation temperature and use the number of plants infected as a criterion, they would assume the following rank: Khapli, Einkorn, Kota, Kubanka, Kanred, Little Club, Marquis, and Turkey Red.

With 2 exceptions, practically 100 per cent of the plants of all varieties incubated at 20° C. for 48 hours produced uredinia typical for that variety. The number of uredinia was greater on all varieties at 20° than at 15°, showing that temperature played an important role during incubation in determining the number of plants infected and the amount of rust. The time required for the flecks and subsequent formation of the uredinia at 20° was somewhat shorter than that required at the lower temperature of 15°.

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A temperature of 25° C. was the optimum for incubation as a large number of flecks or pustules were produced on the plants of all varieties. The period of incubation was also shortened since 6 days after inoculation uredinia were developing in many instances.

An incubation temperature of 30° C. lowered the number of plants which became infected and the degree of infection to a point almost equal to that found at a temperature of 15°. The period of incubation is also lengthened. In only one or two instances 30° was more favorable for infection than 15°. This relation was reversed with other varieties.

No influence from the various incubation temperatures was noted on the types of infection produced. These remained constant for the varieties in every instance. However, the number of plants infected and the number of uredinia were notably changed at the different temperatures. As has been pointed out before, Khapli, the most resistant to the development of rust, became easily infected, while others, like Turkey Red, susceptible to rust, were not so easily infected.

Experiment 2.—This experiment was a repetition of Experiment 1 except that a temperature of approximately 12.5° C. was maintained instead of 15° in one of the incubation chambers. Also several other wheat varieties were included. The plants were more vigorous than those in the preceding experiment owing to a greater amount of sunshine prevailing during this period. The combination of more vigorous plants and increased sunshine resulted in a higher per cent of infection, especially at 30°.

The mean temperature in the greenhouse in which the plants were benched after incubation was 23.1° C. for the period of the experiment, over 4 degrees lower than in Experiment 1. This fact probably accounts for the somewhat slower development of the uredinia. The total number of hours of sunshine for the period of Experiment 2 was 129.6 hours, a daily mean of 9.3 hours, which is an average of 1.7 hours more sunshine per day than prevailed during the course of Experiment 1. It should also be noted that 5 readings were made instead of 4 during the course of the experiment, a summary of which is given in Table 4.

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TABLE 4.—*Influence of incubation temperature on infection of wheat seedlings by Puccinia graminis tritici. Form III*

Experiment 2

Variety	Days after inoculation	Per cent of plants infected at				Degrees of infection at				Types of infection at			
		12.5°C.	20°C.	25°C.	30°C.	12.5°C.	20°C.	25°C.	30°C.	12.5°C.	20°C.	25°C.	30°C.
Little Club C.I.No.4066	5	0	*	*	*	...	1	4–5	1	...	F	F	F
	7	0	84	100	67	...	1–4	4–5	1–2	...	P	P	P
	9	0	96	100	73	...	1–4	4–5	1–2	...	4	4	4
	12	0	100	100	73	...	1–4	4–5	1–2	...	4	4	4
	14	0	100	100	73	...	1–4	4–5	1–2	...	4	4	4
Marquis C.I.No.3641	5	0	*	*	*	...	2–5	2–5	1–3	...	F	F	F
	7	0	100	92	100	...	2–5	5	1–3	...	P	P	P
	9	0	100	96	100	...	2–5	5	1–3	...	4	4	4
	12	0	100	96	100	...	2–5	5	1–3	...	4	4	4
	14	0	100	96	100	...	2–5	5	1–3	...	4	4	4
Kanred C.I.No.5146	5	0	*	*	*	...	1–4	2–5	2–3	...	F	F	F
	7	0	100	100	74	...	2–4	3–5	2–3	...	P	P	P
	9	0	100	100	74	...	2–5	3–5	2–3	...	4	4	4
	12	0	100	100	74	...	2–5	3–5	2–3	...	4	4	4
	14	0	100	100	74	...	2–5	3–5	2–3	...	4	4	4
Turkey Red C.I.No.1558	5	0	*	*	*	...	2–5	3–5	2	...	F	F	F
	7	0	100	100	65	...	2–5	3–5	1–2	...	P	P	P
	9	0	100	100	76	...	2–5	3–5	1–2	...	3	3	3
	12	0	100	100	76	...	2–5	3–5	1–2	...	3–4	3–4	3–4
	14	0	100	100	76	...	2–5	3–5	1–2	...	3–4	3–4	3–4
Kota C.I.No.6248	5	0	*	*	*	...	1–4	1–4	1–2	...	F	F	F
	7	0	88	100	100	...	1–4	1–4	1–3	...	P	P	P
	9	0	100	100	100	...	1–4	1–4	1–3	...	3	3	3
	12	0	100	100	100	...	1–4	1–4	1–3	...	3	3–4	3
	14	0	100	100	100	...	1–4	1–4	1–3	...	3–4	3–4	3–4
Arnautka C.I.No.1493	5	0	*	*	*	...	1–4	1–5	1–3	...	F	F	F
	7	0	100	95	100	...	1–4	1–5	1–3	...	F	F	F
	9	0	100	100	100	...	1–4	1–5	1–3	...	F	F	F
	12	0	100	100	100	...	1–4	1–5	1–3	...	1	1	1
	14	0	100	100	100	...	1–4	1–5	1–3	...	1	1	1
Kubanka C.I.No.1440	5	0	*	*	*	...	1–2	1–5	1	...	F	F	F
	7	10	95	100	100	1–2	2–4	1–5	1	F	F	F	P
	9	10	95	100	100	1–2	2–4	1–5	1	P	P	P	P
	12	10	95	100	100	1–2	2–4	1–5	1	X	X	X	X
	14	10	95	100	100	1–2	2–4	1–5	1	X	X	X	X
Acme C.I.No.5284	5	0	*	*	*	...	1–5	4–5	1–3	...	F	F	F
	7	4	87	100	100	2	1–5	4–5	1–3	F	P	P	F–P
	9	4	100	100	100	2	1–5	4–5	1–3	P	4	4	4
	12	4	100	100	100	2	1–5	4–5	1–3	4	4	4	4
	14	4	100	100	100	2	1–5	4–5	1–3	4	4	4	4
Einkorn	5	0	*	*	*	...	2	1–5	1–4	...	F	F	F
	7	0	100	100	100	...	1–5	1–5	1–4	...	P	P	P
	9	0	100	100	100	...	1–5	1–5	1–4	...	3–4	4	4
	12	0	100	100	100	...	1–5	1–5	1–4	...	4	4	4
	14	0	100	100	100	...	1–5	1–5	1–4	...	4	4	4
Emmer C.I.No.3686	5	0	*	*	0	...	1	1	...	...	F	F	...
	7	0	65	92	83	...	1–2	1–3	1–2	...	F	F	F
	9	5	75	96	96	1	1–2	1–3	1–2	F	1	1	F
	12	5	80	100	96	1	1–2	1–3	1–2	F	1	1	1
	14	5	80	100	96	1	1–2	1–3	1–2	1	1	1	1
Khapli C.I.No.4013	5	0	*	*	*	...	1–5	1–5	1	...	F	F	F
	7	0	100	100	100	...	1–5	1–5	1	...	F	F	F
	9	0	100	100	100		1–5	1–5	1		1	1	1

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An incubation temperature of 12.5° C. appeared to be below the minimum for all varieties except Kubanka, Acme, and Emmer. Only a few plants of these varieties became infected with a trace of rust, the period of incubation being longer than at the temperature of 15° in Experiment 1.

A temperature of 25° C. during 48 hours incubation was the optimum as judged by the period of incubation, the number of plants infected, and the amount of rust developed. As in Experiment 1, an incubation temperature of 20° was the next most favorable temperature. A much larger percentage of infection occurred on all the varieties at 30° than at the same temperature in Experiment 1. On the whole, the percentage of infection and amount of rust at all the incubation temperatures, except 12.5°, was greater than in the preceding experiment and can be correlated in part with the increased amount of sunshine. No differences were noted in the types of infection produced on each individual variety.

INFLUENCE OF INCUBATION TEMPERATURE ON INFECTION OF WHEAT SEEDLINGS BY PUCCINIA GRAMINIS TRITICI FORM IX

Experiment 3.—On January 16, 1923, 150 seedling plants, 7 days old, of each of the wheat varieties listed in Table 5, were inoculated by hand and 30 placed in each incubation chamber for 48 hours. The incubation chambers were maintained at the temperatures of 10°, 15°, 20°, 25°, and 30° C. After incubation the plants were trimmed to one leaf and benched. The mean temperature of the greenhouse for the period of this experiment was 22.7°. Only 82.1 hours of sunshine was recorded for the period of the experiment, a daily mean of 5.9 hours. It was very noticeable that when the plants incubated at the temperatures of 10° and 15° were placed on a bench of the warm greenhouse, they were stimulated to a more rapid growth than the others incubated at the higher temperatures. The results of the experiment are given in Table 5.

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e 5.—*Influence of incubation temperature on infection of wheat seedlings by Puccinia graminis tritici Form IX*

Experiment 3

Variety	Days after inoculation	Per cent of plants infected at					Degrees of infection at					Types of infection at				
		10°C.	15°C.	20°C.	25°C.	30°C.	10°C.	15°C.	20°C.	25°C.	30°C.	10°C.	15°C.	20°C.	25°C.	30°C.
Club	6	0	0	3	0	0	...	...	1	...	...	...	...	F	...	...
No. 4066	9	0	10	20	24	0	...	1	1	1-2	...	...	3	3	3	...
	14	0	10	20	24	0	...	1	1	1-2	...	...	4	4	4	...
iis	6	0	0	43	3	0	...	...	1-3	1	...	...	...	F	F	...
No. 3641	9	45	20	71	18	0	1	1	1-3	1	...	3	3	3	3	...
	14	45	20	71	18	0	1	1	1-3	1-2	...	4	4	4	4	...
d	6	0	0	0	0	0	...	...	...	...	...	...	...	...	...	...
No. 5146	9	22	17	33	43	24	1	1	1-3	1-2	1-2	0;	0;	0;	0;	0;
	14	22	17	33	43	24	1	1	1-3	1-2	1-2	0;	0;	0;	0;	0;
y Red	6	0	3	34	12	0	...	1	1-3	1	...	...	F	F	F	...
No. 1558	9	33	30	86	24	0	1-2	1-3	1-3	1	...	3	3	3	3	...
	14	33	30	86	24	0	1-2	1-3	1-3	1	...	3	3	3	3	...
	6	0	0	40	11	0	...	...	1-3	1	...	...	...	F	F	...
No. 5878	9	11	19	60	43	0	1	1	1-3	1	...	F	F	3	3	...
	14	11	19	60	43	0	1	1	1-3	1	...	3	3	3	3	...
ka	6	0	0	33	20	0	...	...	1-3	1-2	...	...	...	F	F	...
No. 1494	9	40	55	70	20	3	1-2	1-3	1-3	1-3	1	F	F-3	3	3	3
	14	40	55	70	20	3	1-2	1-3	1-3	1-3	1	4	4	4	4	4
m	6	0	0	24	45	0	...	...	1-3	1-2	...	...	...	F	F	...
No. 5296	9	0	23	52	52	3	...	1-2	1-3	1-3	1	...	F	X	X	X
	14	0	23	52	52	3	...	1-2	1-3	1-3	1	...	X	X	X	X

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TABLE 5 CONCLUDED.—*Influence of incubation temperature on infection of wheat seedlings by Puccinia graminis tritici Form IX*

Experiment 3

Variety	Days after inoculation	Per cent of plants infected at					Degrees of infection at					Types of infection at				
		10°C.	15°C.	20°C.	25°C.	30°C.	10°C.	15°C.	20°C.	25°C.	30°C.	10°C.	15°C.	20°C.	25°C.	30°C.
Speltz Marz	6	0	0	29	0	0	...	...	1–2	...	...	...	...	F	...	...
C. I. No. 6236	9	0	15	45	0	0	...	1	1–3	...	...	...	3	3	...	...
	14	0	15	45	0	0	...	2	1–3	...	...	...	3–4	4	...	...
Kubanka	6	0	0	14	10	0	...	...	1	1	...	...	...	F	F	...
C. I. No. 1440	9	0	0	18	10	0	...	...	1	1	...	...	...	X	X	...
	14	0	0	18	10	0	...	...	1	1	...	...	...	X	X	...
Acme	6	3	0	53	17	4	1	...	1–2	1	1	F	...	F	F	F
C. I. No. 5284	9	47	29	87	37	7	1	1	1–3	1	1	F–3	3	3	3	3
	14	47	29	87	37	7	1	1	1–3	1–2	1	3–4	4	4	4	4
Einkorn	6	0	0	90	38	0	...	...	1–4	1	...	...	...	F	F	...
C. I. No. 2433	9	4	7	97	55	0	2	1	1–5	1–3	...	3	3	3	3	...
	14	4	7	97	55	0	2	1	1–5	1–3	...	3	3–4	4	4	...
Emmer	6	0	0	17	33	0	...	...	1–4	1–3	...	...	...	F	F	...
C. I. No. 3686	9	3	18	80	47	0	1	1	1–4	1–3	...	3	F–3	F–3	3	...
	14	3	18	80	47	0	1	1	1–4	1–3	...	3	3	3–4	3–4	...
Khapli	6	0	0	86	80	25	...	...	1–4	1–4	1	...	...	F	F	F
C. I. No. 4013	9	0	7	97	100	56	...	1	1–4	1–4	1–2	...	F	F–1	F–1	F–1
	14	0	7	97	100	56	...	1	1–4	1–4	1–2	...	1	1	1	1

For explanation of symbols used in this table see page 9.

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At the incubation temperature of 10° C. the majority of the varieties became infected with a trace of rust. In no instance did the percentage of infection exceed 50 per cent of the plants of any one variety. At 15° all varieties became infected but the number of plants infected and the amount of rust did not exceed that produced at 10°. Taking the varieties as a whole, more infection and a greater number of uredinia occurred at 20° and 25°, while at 30° infection took place as a rule on only a few plants of some varieties. The optimum incubation temperature for Form IX appears to be 20°, altho 25° is almost equally favorable for some varieties, as for example, Khapli. On the whole a very low percentage of infection occurred as compared with that obtained with Form III (Experiment 2), due in part to the small amount of sunshine prevailing during the course of the experiment.

Experiment 4.—This experiment was a repetition of Experiment 3. The same temperatures were maintained in the incubation chambers, and after the plants were benched the same mean temperatures occurred for the period the plants were in the greenhouse. The total hours of sunshine recorded for the period of the experiment were 95.0 hours, a daily mean of 6.8 hours. In other words, all factors influencing the results were, with the exception of sunlight, as nearly the same as it was possible to maintain them. The results as tabulated in Table 6 agree in the main with those obtained in Experiment 3. As can be noted, in only one or two instances did all the plants of any one variety become 100 per cent infected even at the optimum temperature for infection. In both experiments the number of plants infected and the number of uredinia were much smaller than those obtained with Form III. In experiments to be reported later, this same fact will be pointed out.

In conclusion it can be stated that as far as the influence of incubation temperatures on infection was concerned, the

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So far as can be determined the period of incubation at the various temperatures with both biologic forms were the same. Furthermore, these incubation temperatures had no influence whatever on the type of infection developed. These were fixed for the biologic form in question. The main differences noted were in the percentage of plants infected and in the amount of rust produced at the various incubation temperatures.

The reaction of the host plants to rust varied also. One variety responded at a stated temperature with one form of rust and not with another. Moreover, some varieties became more quickly infected than others irrespective of their relative susceptibility to these biologic forms. Still others had a limited range of temperatures at which infection might occur, while others did not seem to be so limited.

Experiment 5.—As has been shown in Experiments 3 and 4, Kanred was very resistant to biologic Form IX, while Turkey Red was susceptible. The object of this experiment was to study the behavior of Form IX on a number of more or less related varieties.

Kanred is a single head selection from Crimean (C. I. No. 1435), Turkey Red is the name most commonly used for the Crimean group of hard winter wheats grown in the United States, while Blackhull was originated as a selection from a field of Turkey Red. Of the 5 lots of Kanred seed used in this experiment all bear the same Cereal Investigations number, altho they were grown in different localities. Three lots of Turkey Red seed bearing 2 different Cereal Investigations numbers, together with Turkey Red (Nebraska check) used by the Department of Agronomy for a number of years as a check for their selected strains of Turkey Red, 2 of which were included in this experiment, were used.

On March 9, 1923, 150 seedling plants, 7 days old, of each of the varieties listed in Table 7, were inoculated by hand. Thirty plants of each variety were then incubated for 48 hours at the temperatures of 10°, 15°, 20°, 25°, and 30° C. After incubation they were trimmed and benched in a greenhouse the mean temperature of which was 24°. The total hours of sunshine recorded for the period of the experiment was 87.3 hours, a daily mean of 6.2 hours.

Only the results of the final reading are listed in Table 7, as the period of incubation and development of the uredinia was similar to that reported in Experiments 3 and 4. Altho the Kanred seed of the same Cereal Investigations number

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TABLE 6.—*Influence of incubation temperature on infection of wheat seedlings by Puccinia graminis tritici Form IX*

Experiment 4

Variety	Days after inoculation	Per cent of plants infected at					Degrees of infection at					Types of infection at				
		10°C.	15°C.	20°C.	25°C.	30°C.	10°C.	15°C.	20°C.	25°C.	30°C.	10°C.	15°C.	20°C.	25°C.	30°C.
Little Club	6	0	17	47	10	0	...	1	1-3	1	...	...	F	F-P	P	...
C. I. No. 4066	9	0	17	50	10	0	...	1-2	1-3	1	...	...	3	4	3	...
	14	0	17	50	10	0	...	1-2	1-3	1	...	...	4	4	4	...
Marquis	6	0	13	33	57	0	...	1	1-2	1-2	...	...	F	F-P	F-P	...
C. I. No. 3641	9	13	30	33	57	0	1	1	1-2	1-2	...	3	3	3	3-4	...
	14	13	30	33	57	0	1	1	1-2	1-2	...	4	4	4	4	...
Kanred	6	0	3	7	3	0	...	1-2	1-2	1-2	...	...	0;	0;	0;	...
C. I. No. 5146	9	3	7	10	7	0	1	1-2	1-2	1-2	...	0;	0;	0;	0;	...
	14	3	7	10	7	0	1	1-2	1-2	1-2	...	0;	0;	0;	0;	...
Turkey Red	6	0	7	30	27	0	...	1	1	1-2	...	...	F	F	F-P	...
C. I. No. 1558	9	7	17	37	27	0	1	1	1	1-2	...	3	3	3	3	...
	14	7	17	37	27	0	1	1	1-2	1-2	...	4	4	4	4	...
Kota	6	13	10	24	47	0	1	1	1	1	...	F	F	F	F-P	...
C. I. No. 5878	9	23	17	31	47	0	1	1	1	1	...	3	3	3	3	...
	14	23	17	31	47	0	1	1	1	1	...	3	3	3	3	...
Arnautka	6	0	23	50	43	0	...	1-2	1-2	1-3	...	...	F	F-P	F-P	...
C. I. No. 1494	9	30	53	67	43	0	1-2	1-2	1-2	1-3	...	3	3	3	3	...
	14	30	53	67	43	0	1-2	1-2	1-2	1-3	...	4	4	4	4	...
Mindum	6	10	13	50	43	5	1	1	1-3	1-3	1	F	F	F-P	F-P	F
C. I. No. 5296	9	43	43	63	43	5	1	1	1-3	1-3	1	X	X	X	X	X
	14	43	43	63	43	5	1	1	1-3	1-3	1	X	X	X	X	X

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TABLE 6 CONCLUDED.—*Influence of incubation temperature on infection of wheat seedlings by Puccinia graminis tritici Form IX*

Experiment 4

Variety	Days after inoculation	Per cent of plants infected at					Degrees of infection at					Types of infection at				
		10°C.	15°C.	20°C.	25°C.	30°C.	10°C.	15°C.	20°C.	25°C.	30°C.	10°C.	15°C.	20°C.	25°C.	30°C.
Speltz Marz	6	0	3	7	18	0	...	1	1	1	...	...	F	P	P	...
C. I. No. 6236	9	20	13	10	30	0	1	1	1	1-2	...	3	3	3	3	...
	14	20	13	10	30	0	1	1	1	1-2	...	4	4	4	4	...
Kubanka	6	3	7	20	48	0	1	1	1-2	1-2	...	F	F	F-P	F-P	...
C. I. No. 1440	9	23	27	57	52	0	1	1	1-2	1-2	...	X	X	X	X	...
	14	23	27	57	52	0	1-2	1-2	1-2	1-2	...	X	X	X	X	...
Acme	6	21	38	48	31	7	1-2	1-2	1-3	1-2	1	F	F	P	F-P	P
C. I. No. 5284	9	52	59	63	31	11	1-2	1-2	1-3	1-2	1	3	3	3	3	3
	14	52	59	63	31	11	1-2	1-2	1-3	1-2	1	4	4	4	4	4
Einkorn	6	0	10	57	40	0	...	1	1-2	1	...	...	P	P	P	...
C. I. No. 2433	9	0	27	57	40	0	...	1	1-2	1	...	...	3	3	3	...
	14	0	27	57	40	0	...	1	1-2	1	...	...	4	4	4	...
Emmer	6	3	17	21	29	0	1	1	1-2	1-3	...	F	F	F-P	P	...
C. I. No. 3686	9	14	20	34	29	0	1	1	1-2	1-3	...	3	3	3	3	...
	14	14	20	34	29	0	1	1	1-2	1-3	...	4	4	4	4	...
Khapli	6	10	7	33	48	3	1	1-2	1-2	1-2	1	F	F	F	F	F
C. I. No. 4013	9	52	63	40	48	7	1	1-2	1-2	1-2	1	F-1	F-1	1	F-1	F-1
	14	52	63	40	48	7	1	1-2	1-3	1-2	1	1	1	1	1	1

For explanation of symbols used in this table see page 9.

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incubation temperature on infection of a number of related wheat s of the Crimean group by Puccinia graminis tritici Form IX

Experiment 5

Source	Per cent of plants infected at					Degrees of infection at					Types of infection at				
	10°C.	15°C.	20°C.	25°C.	30°C.	10°C.	15°C.	20°C.	25°C.	30°C.	10°C.	15°C.	20°C.	25°C.	30°C.
casin, Mont.	29	29	17	68	70	1	1	1	1	1	0;	0;	0;	0;	0;
hattan, Kan.	11	34	45	73	63	1	1	1	1	1	0;	0;	0;	0;	0;
re, Mont.	11	43	42	70	46	1	1	1	1	1	0;	0;	0;	0;	0;
n, Colo.	11	20	45	56	70	1	1	1	1	1	0;	0;	0;	0;	0;
oln, Neb.	20	20	57	97	87	1	1–2	1–3	1–3	1–2	0;	0;	0;	0;	0;
casin, Mont.	57	47	63	89	11	1–2	1–2	1–2	1–4	1	3	3–4	3–4	3–4	3–4
o, Ore.	17	23	52	76	11	1	1–2	1–2	1–4	1	3	3	3–4	3–4	3–4
s, Kan.	31	48	63	77	48	1	1–2	1–2	1–4	1–2	3	3–4	3–4	3–4	3–4
oln, Neb.	43	47	40	65	33	1	1–2	1	1–4	1	3	3–4	3–4	3–4	3–4
oln, Neb.	38	80	46	83	48	1	1–3	1–2	1–4	1	3	3–4	3–4	3–4	3–4
oln, Neb.	83	83	77	93	72	1–2	1–3	1–3	1–4	1	3–4	3–4	3–4	3–4	3–4
oln, Neb.	33	63	50	73	23	1	1–2	1–3	1–3	1	3	3–4	3–4	3–4	3
oln, Neb.	17	27	41	90	73	1	1–2	1–2	1–4	1	3–4	4	3–4	4	4

ed in this table see page 9.

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had been grown in 5 different localities, no appreciable differences were noted in their individual reactions to Form IX at the various incubation temperatures. The number of plants infected and the amount of rust which developed after incubation appeared to be greater at the temperatures of 25° and 30° C. than were reported for Kanred at the same temperatures in Experiments 3 and 4.

With the 6 numbers of Turkey Red, rather large variations in the percentage of infection occurred. Another fact which appears to be quite characteristic of Turkey Red in its reaction to both biologic forms investigated was that at 30° C. it was not as easily infected as Kanred.

The percentage of the plants infected and the amount of rust were smaller with Blackhull than with either Kanred or Turkey Red (Pl. 8, C). The same was true of Crimean (Pl. 8, D).

Judging from the number of plants infected and the amount of rust and type of infection, Blackhull appears to be slightly more resistant than Turkey Red. However, no great differences existed. On the leaves of Crimean larger uredinia were produced than on either Blackhull or Turkey Red. In the case of Kanred only hypersensitive flecks developed.

INFLUENCE OF THE SOURCE OF INOCULUM ON THE DEVELOPMENT OF PUCCINIA GRAMINIS TRITICI ON CERTAIN WHEAT VARIETIES FORM III

Experiment 6.—This experiment was carried out to answer the question as to whether or not the behavior of a biologic form on its host could be changed by using different sources of inoculum. Three distinct sources were used, as follows: (1) from the stock cultures grown in the greenhouse on Little Club, (2) from the same host as that inoculated, and, (3) from Khapli.

Thirty seedling plants of each variety were inoculated with each inoculum in the usual manner and incubated for 48 hours at a temperature of approximately 25° C. After incubation they were trimmed and set on a bench in a greenhouse the mean temperature of which was 24.5° for the period of the experiment. The total hours of sunshine recorded for the period of the experiment was 79.1 hours, a daily mean of 5.6 hours.

The results listed in Table 8 show rather conclusively that the same type of infection occurred on the different varieties irrespective of the source of the inoculum. The

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lower percentage of infection when rust from Khapli was used was due to smaller amounts of inoculum placed on the inoculated leaves.

TABLE 8.—*Influence of the source of inoculum on the development of Puccinia graminis tritici on certain wheat varieties Form III*

Experiment 6

Variety	Source of inoculum	Per cent of plants infected	Degrees of infection	Types of infection
Little Club	Stock	100	5	4
C. I. No. 4066	Little Club	100	3–5	4
	Khapli	60	1–3	4
Marquis	Stock	100	5	4
C. I. No. 3641	Marquis	100	4	4
	Khapli	68	1–3	4
Kanred	Stock	100	3–5	4
C. I. No. 5146	Kanred	100	3–5	4
	Khapli	82	1–3	4
Turkey Red	Stock	100	5	3–4
C. I. No. 1558	Turkey Red	100	5	3–4
	Khapli	70	1–2	3–4
Kota	Stock	100	5	3–4
C. I. No. 6248	Kota	100	2–5	3–4
	Khapli	67	1–2	3–4
Kubanka	Stock	100	4–5	X
C. I. No. 1440	Kubanka	100	4–5	X
	Khapli	100	1–2	X
	Stock	100	5	3–4
Einkorn	Einkorn	100	5	3–4
	Khapli	87	1–3	3–4
Khapli	Stock	100	5	1
C. I. No. 4013	Khapli	100	1–3	1
	Kubanka	100	5	1

For explanation of symbols used in this table see page 9.

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INFLUENCE OF ENVIRONMENTAL CONDITIONS UNDER WHICH SEED OF THE DIFFERENTIAL HOSTS WAS GROWN, ON INFECTION AND SUBSEQUENT DEVELOPMENT ON THE HOST PROGENY, OF PUCCINIA GRAMINIS TRITICI FORM III AND FORM IX

Experiments 7 and 8.—In both experiments seedling plants 7 days old, of the various differential hosts listed in Table 9, were inoculated (50 each in 1922 and 30 in 1923) and incubated for 48 hours. They were then trimmed and placed on a bench in the greenhouse. The mean temperature of the greenhouse for the period of the experiment in 1922 was 22° and in 1923, 24° C. The total hours of sunshine for the period of the experiment in 1922 was 80.9, a daily mean of 5.8 hours; while in 1923 the total hours of sunshine recorded was 134.7, a mean of 9.6 hours. Thus, a total of 53.8 hours more of sunshine prevailed during the experiment in 1923 than in the experiment run in 1922.

During the growth of the plants in both experiments, notes were made on the plumpness of the seed planted and the development of the resulting seedlings. Characteristic differences were noted. A few illustrations here will suffice to demonstrate this fact. In the case of the Little Club seed grown at Moro and Corvallis, Oregon, the seedlings presented a much shorter and wider leaf than the other plants. Even at the conclusion of the experiment this characteristic was very evident. On the other hand, no gross morphological differences were noted between the seedlings of Marquis and they reacted equally to the 2 biologic forms used. The seedlings of the other differential hosts either showed characteristics like those described for Little Club or no differences were noted as in the case of Marquis. Of course, an occasional mixture of seed was encountered and these were discarded when observed.

The results given in Table 9 are, on the whole, uniform in respect to the number of plants infected, the amount of rust, and the type of infection produced by the 2 biologic forms on the seedlings of the differential hosts, irrespective of the Cereal Investigations number and the locality where the seed was grown (Pls. 2 to 8).

We can conclude from these experiments that the environmental factors under which the seed of the differential hosts was grown had no influence in changing the reaction of the progeny to a definite biologic form in any of the experiments

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reported on. In this connection it would be interesting to determine how one biologic form obtained from different localities would behave on the various differential hosts.

TABLE 9.—*Influence of environmental conditions under which seed of the differential hosts was grown, on infection and subsequent development on the host progeny, of Puccinia graminis tritici*

Form III and Form IX

Experiments 7 and 8

Variety	Cereal investigations number	Locality grown and crop year	Per cent of plants infected		Degrees of infection		Types of infection	
			Form III	Form IX	Form III	Form IX	Form III	Form IX
Little Club	4066	Moccasin, Mont. 1921	96	93	1–4	1–3	4	4
	4066	Moccasin, Mont. 1921	92	90	1–4	1–2	4	4
	4066	Moro, Ore. 1921	100	100	1–4	1–2	4	4
	4066	Corvallis, Ore. 1919	100	93	1–4	1–2	4	4
	4066	Lincoln, Neb. 1922	...	100	...	1–3	...	4
Marquis	3641	Moccasin, Mont. 1921	100	100	1–4	1–3	4	4
	3641	Moccasin, Mont. 1921	100	100	1–4	1–4	4	4
	3276	Aberdeen, Ida. 1921	100	98	1–5	1–3	4	4
	3641	Unknown	98	100	1–4	1–3	4	4
	3641	Lincoln, Neb. 1922	...	97	...	1–4	...	4
Kanred	5146	Moccasin, Mont. 1921	98	68	1–4	1	4	0;
	5146	Manhattan, Kan. 1919	100	78	1–4	1	4	0;
	5146	Havre, Mont. 1921	98	70	1–4	1	4	0;
	5146	Akron, Colo. 1921	90	56	1–4	1	4	0;
	5146	Lincoln, Neb. 1922	98	97	1–4	1–3	4	0;
Turkey Red	1558	Moccasin, Mont. 1921	98	89	1–4	3–4	4	3–4
	1571	Moro, Ore. 1921	98	76	1–4	1–2	4	3–4
	1558	Hays, Kan. 1921	98	77	1–4	1–4	4	3–4
Kota	6248	Moccasin, Mont. 1921	98	93	1–3	1–3	3–4	3–4
	6248	Moccasin, Mont. 1921	98	90	1–3	1–3	3–4	3–4
	5878	Dickinson, N. D. 1920	100	100	1–3	1–3	3–4	3–4
	6248	Lincoln, Neb. 1922	...	97	...	1–4	...	3–4
	5878	Minnesota	...	100	...	1–4	...	3–4
	5878	North Dakota 1922	...	100	...	1–4	...	3–4
Arnautka	1493	Moccasin, Mont. 1921	90	100	1–3	1–4.	1	4
	4064	Moccasin, Mont. 1921	95	100	1–3	1–4	1	4
	4072	Corvallis, Ore. 1919	97	96	1–3	1–4	1	4
	1493	Akron, Colo.	56	100	1–2	1–4	1	4
	4064	Minnesota	...	100	...	1–4	...	4
	1494	North Dakota 1922	...	100	...	2–4	...	4
	4064	South Dakota 1922	...	97	...	1–4	...	4
Mindum	5296	Moccasin, Mont. 1921	75	100	1–2	1–4	0;	X
	5296	Cheyenne, Wyo. 1920	93	97	1–3	1–2	0;	X
	5296	Dickinson, N. D. 1920	84	100	1–2	1–3	0;	X
	5296	Dickinson, N. D. 1920	...	100	...	1–3	...	X

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TABLE 9 CONCLUDED.—*Influence of environmental conditions under which seed of the differential hosts was grown, on infection and subsequent development on the host progeny, of Puccinia graminis tritici*

Form III and Form IX

Experiments 7 and 8

Variety	Cereal investigations number	Locality grown and crop year	Per cent of plants infected		Degrees of infection		Types of infection	
			Form III	Form IX	Form III	Form IX	Form III	Form IX
Speltz Marz	....	Unknown	100	100	1–4	1–3	3	4
	6236	Unknown	...	69	...	1–3	...	4
Kubanka	1440	Moccasin, Mont. 1921	100	100	1–3	1–4	X	X
	4043	Moccasin, Mont. 1921	87	100	1–3	1–3	X	X
	1440	Dickinson, N. D. 1920	88	100	1–3	1–3	X	X
	2094	Unknown	88	90	1–3	1–2	X	X
	2094	Unknown	95	100	1–3	1–4	X	X
	1440	Lincoln, Neb. 1922	...	97	...	1–4	...	X
	1440	North Dakota 1922	...	93	...	1–3	...	X
	6519	North Dakota 1922	...	100	...	1–2	...	X
	1440	Minnesota	...	97	...	1–3	...	X
Acme	5284	Moccasin, Mont. 1921	100	93	1–3	1–3	4	3–4
	5284	Mandan, N. D. 1920	100	100	1–3	1–4	4	3–4
	5284	Akron, Colo. 1921	97	97	1–3	1–4	4	3–4
	5284	Unknown	93	100	1–3	1–3	4	3–4
	5284	North Dakota 1922	...	90	...	1–3	...	3–4
	5284	Minnesota	...	90	...	1–3	...	3–4
Einkorn	....	Dickinson, N. D. 1921	100	93	1–3	1–2	4	4
	2433	Dickinson, N. D. 1920	100	100	1–4	1–3	4	4
	2433	Unknown	...	100	...	1–4	...	4
	2433	Minnesota	...	100	...	1–4	...	4
Emmer	3686	Moccasin, Mont. 1921	90	100	1–3	1–3	0;–1	4
	3686	St. Paul, Minn. 1920	74	80	1	1–2	0;–1	4
	3686	Unknown	81	93	1–2	1–2	0;–1	4
Khapli	4013	Moccasin, Mont. 1921	89	97	1–3	1–3	1	1
	4013	Moccasin, Mont. 1921	94	100	1–3	1–3	1	1
	4013	Highmore, S. D. 1920	87	100	1–3	1–3	1	1
	4013	Unknown	100	100	1–3	1–3	1	1
	4013	Davis, Calif. 1922	...	100	...	1–3	...	1
	4013	Lincoln, Neb. 1922	...	100	...	1–3	...	1

For explanation of symbols used in this table see page 9.

INFLUENCE OF TEMPERATURE ON THE DIFFERENTIAL HOSTS AT DIFFERENT STAGES OF GROWTH

The experiments previously reported on have for the most part dealt with the incubation temperatures suitable for infection by the two biologic forms studied, of wheat seedlings grown in pots. We come now to the study of the influence of temperature not only on infection but also on the subsequent development of rust. At the same time an opportunity was afforded of noting the behavior of the differential hosts at the various temperatures. Four distinct stages in the

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growth of the wheat plant were studied, namely: seedling, stooling, jointing, and heading. Before presenting the data on the environmental factors influencing infection a short account will first be given of the host reaction to these conditions.

Seedling stage.—Thirty-five seeds of each of the varieties listed in Tables 10 and 11 were planted in each can and notes taken on date of emergence, per cent of germination, and seedling development at the various temperatures.

At 5° C. the seedlings emerged in about 3 weeks. By the end of the seventh week the seedlings were from ½ to 4 inches in height and only the primary leaf had developed.

At 10° C. 10 to 12 days were required for the emergence of the seedlings. By the end of the seventh week the seedlings were from 6 to 8 inches in height and from 2 to 3 leaves were fully developed. An excellent growth of the seedlings occurred at this temperature as judged by the dark green color and strong upright habit of the plants.

Only 7 days were required for emergence at 15° C. The seedlings made an excellent growth, having a dark green color and upright habit. At this temperature some differences in the height of the plants of the different varieties were noted. Some varieties were 10 inches in height at the end of the seventh week, while others were only 6 to 8 inches in height. As a rule, 3 or more leaves were present.

At 20° C. the time required for emergence was shortened to 5 days. A good upright growth of the seedlings took place so that by the end of the seventh week some were 10 to 12 inches in height, while others were only 8 inches. A few varieties started to stool. The seedlings had from 4 to 5 leaves fully expanded.

Emergence occurred in 3 days at the temperatures of 25° and 30° C. The plants were not thrifty, being of a light green color and drooping. The most striking characteristic was the very pronounced elongated mesocotyl, especially at 30°. Only a few secondary roots were formed, so that seedlings grown at this temperature did not make a very thrifty growth. The seedlings grown at these temperatures were only 5 to 7 inches in height and with an average of 2 leaves.

Another interesting observation was made with Einkorn and Khapli. At temperatures of 20° C. and below, a very pronounced reddish pigmentation of the culms occurred. This pigmentation did not appear at the temperatures of 25° and 30°.

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With only one or two exceptions the percentage of germination at the temperatures of 5°, 10°, 15°, 20°, and 25° C. was about the same for each variety. However, the time required for germination and emergence varied according to the temperature. At 30° the per cent of germination decreased with all varieties and this was especially noticeable with Turkey Red and Kanred.

At the conclusion of one experiment, the cans planted with Turkey Red and Kanred and held at 30° C. were set out at a lower temperature. During the course of the experiment only a few plants had come up. However, when the soil temperature was lowered, a majority of the seed which had not germinated when held at 30° germinated at this lower temperature (about 20° C.). In this instance it was purely a case of delayed germination due to unfavorable temperatures.

In conclusion it can be stated that with the exception of the seeds planted and held at 30° C. the per cent of germination was about the same at all temperatures altho the time required for germination and emergence varied according to the temperature, being shortest at 25° and 30° and longest at 5°. The best development of the seedlings occurred at 15° and 20°, altho a good but rather slow growth took place at 10°, while at 5° an extremely slow growth occurred. The number of plants included in the experiments was too small to correlate any differences in behavior of the varieties to the various temperatures, altho differences were noted from time to time.

Stooling and jointing stages.—For the study of the influence of temperature on these stages of the growth of the differential hosts, 8 seeds were planted in the cans. The cans were placed on a bench in the greenhouse until the plants started to stool when they were transferred to the various temperature cases. The first year, the plants were placed in the cases when they were about 6 to 8 inches in height and some varieties had just begun to stool. All plants had 4 to 6 leaves fully developed and all were in a good growing condition. The second year the plants were held in the greenhouse on the bench for about 2½ months. At the time these plants were placed in the temperature cases they were about 15 inches tall, with all varieties stooling and most of them jointing.

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At 5° C. all varieties made a slow growth. The average increase in height made for the duration of the experiment was 3 to 9 inches. The Durum wheats appeared to make the best growth at this temperature. A little more rapid growth occurred at 10°. At 15° the spring wheats almost doubled their height during the course of the experiment. The Durum wheats appeared to make the most rapid growth at this temperature. At 20° the plants made an excellent growth, the spring wheats more than doubling their previous height. A few varieties were headed at the conclusion of the experiment.

In all instances the condition of the plants at 25° C. at the conclusion of the experiment was poorer and the growth less than at 20°. The poorer condition of the plants was still more pronounced at 30° and little or no increase in the height of the plants was noticed. Einkorn appears to be very sensitive to high temperatures. In these experiments rarely have any of the Einkorn plants remained alive at 25° and 30° at the conclusion of an experiment. Both Turkey Red and Kanred also suffered from these temperatures and produced only dwarfed plants. The other varieties made some growth at these temperatures but it was not nearly as good as at the lower temperatures. Stooling was rather general at temperatures of 20° and below. Little or no stooling occurred at 25° and 30°. The Durum wheats produced a few stools at every temperature. A temperature of 25° hastened heading, while at 30° heading was inhibited. Thus, as in the case of the seedling plants, the best and most normal development of the plants occurred at 15° and 20°.

Heading stage.—As in the case of the study of the influence of temperature on the differential hosts at the stooling and jointing stages, 4 plants were grown in the cans and held in the greenhouse until about heading time when they were transferred to the temperature cases.

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tures. In fact, temperatures of 25° and 30° had a more inhibiting effect on the plants at the heading stage than at the other stages discussed. Again, the best and most normal development of the plants at the heading stage occurred at 15° and 20°.

INFLUENCE OF TEMPERATURE ON INFECTION AND DEVELOPMENT OF PUCCINIA GRAMINIS TRITICI ON WHEAT PLANTS AT THE SEEDLING STAGE FORM III

Experiment 9.—On March 13, 1922, the cans held at the temperatures of 20°, 25° and 30° C. for several days were seeded with the differential hosts listed in Table 10. The seedlings were inoculated by the spray method when they were 7 days old, at which time the first leaf had developed. During the period the plants were in the cases, a daily mean of 6.5 hours of sunshine prevailed.

Owing to the method of inoculation, 100 per cent infection was not to be expected, so that the total number of plants infected was rather small, as can be seen from Table 10.

TABLE 10.—*Influence of temperature on infection and development of Puccinia graminis tritici on wheat plants at the seedling stage*

Form III

Experiment 9

Variety	Per cent of plants infected at			Degrees of infection at			Types of infection at		
	20°C.	25°C.	30°C.	20°C.	25°C.	30°C.	20°C.	25°C.	30°C.
Little Club C. I. No. 4066	27	22	0	1–2	1–3	...	4	4	...
Marquis C. I. No. 3641	74	11	3	2	1–3	3	4	4	4
Kanred C. I. No. 5146	40	3	0	1–3	2	...	4	4	...
Turkey Red	53	3	8	1–5	1–2	3	4	4	4

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At 30° C. only the first leaf of an occasional plant of a few varieties became infected. A few plants of all varieties but one, were infected at 25°. The number of uredinia was greater than at 30°. On the whole the degree of infection was rather light. At 20° where the plants made their optimum development the highest percentage of infection occurred on all varieties. The amount of rust was greater than at the other temperatures. Both at 20° and 25° uredinia usually occurred on the first leaf, a few on the second, with only an occasional pustule on the third leaf.

While striking differences were noted in the development of the plants, the number of plants infected, and the amount of rust at the various temperatures, in no instance was the type of infection altered by changes in temperature. The results of this experiment show that the conditions under which the plants are grown play a considerable part in infection and subsequent development of rust. The seedlings making the most normal and rapid growth rust most readily.

When the results obtained in Experiment 2 are compared with the results obtained here, it will be noted that the inoculated plants grown normally and subjected to an incubation temperature of 30° C. for 48 hours and then returned to lower temperatures produced a much higher percentage of infection. Thus, an incubation temperature of 30° for a short period gives a much higher per cent of infection than when plants are subjected to a temperature of 30° both before and after inoculation. In conclusion it can be stated that the optimum temperature for infection and subsequent development of rust was 20°.

INFLUENCE OF TEMPERATURE ON INFECTION AND DEVELOPMENT OF PUCCINIA GRAMINIS TRITICI ON WHEAT PLANTS AT THE SEEDLING STAGE FORM IX

Experiment 10.—Having installed the low temperature apparatus in the greenhouse during the summer of 1922, it

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11.—*Influence of temperature on infection and development of Puccinia graminis tritici on wheat plants at the seedling stage*

Form IX

Experiment 10

	Per cent of plants infected at						Degrees of infection at						Types of infection at					
	5°C.	10°C.	15°C.	20°C.*	25°C.	30°C.	5°C.	10°C.	15°C.	20°C.	25°C.	30°C.	5°C.	10°C.	15°C.	20°C.	25°C.	30°C.
56	0	0	0	4	28	3	...	...	...	1	1–3	2	...	...	...	4	4	4
46	0	0	0	0	10	0	...	...	...	...	1	...	...	...	...	...	0;	...
58	0	0	0	0	48	4	...	...	...	...	1–4	4	...	...	...	...	4	4
93	0	0	11	11	62	5	...	...	1	3	1–3	1	...	...	3	4	3	3–4
96	0	0	0	11	50	0	...	...	...	1	1–3	...	...	...	...	X	X	...
40	0	0	0	4	10	0	...	...	...	2	1	...	...	...	...	X	X	...
33	0	0	3	8	31	0	...	...	1	3	1–2	...	...	...	3	3	3	...
13	0	0	0	32	29	10	...	...	...	1	1	1	...	...	...	1	1	...

*lated, as first inoculation failed.

*lanation of symbols used in this table see page 9.

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Only a few plants of some varieties were infected with a trace of rust at 30° C. Considerably more rust occurred at 25°, and the plants made a more favorable growth than at the higher temperature of 30°.

The plants made a splendid growth at 20° C. and at the conclusion of the experiment some of the varieties were stooling. For some unknown reason, the first inoculation failed to produce any rust whatever, so this case was reinoculated 2 weeks later. Thus, at the conclusion of the experiment less rust was present than should be expected at this temperature, so that the results cannot be correlated with those obtained at the other temperatures.

Only an occasional plant of 2 varieties became infected with a trace of rust at 15° C. At the conclusion of the experiment, 30 days after inoculation, no rust appeared on the plants held at 5° and 10°. However, the plants in the 5° case were only 1 to 4 inches in height, and in many instances the first leaf had not expanded. Here we find that when plants are held at a constant temperature of 10° before and after inoculation, no infection occurs, altho infection did occur when plants were subjected to an incubation temperature of 10° for 48 hours and then removed to temperatures more normal for the development of the plants.

INFLUENCE OF TEMPERATURE ON DEVELOPMENT OF PUCCINIA GRAMINIS TRITICI ON WHEAT PLANTS AT THE SEEDLING STAGE FORM IX

Experiment 11.—In Experiment 10 it was found that at the temperatures of 5° and 10° C. no infection was obtained. The object of this experiment was to determine whether or not these temperatures were too low for the development of rust, when the plants were inoculated and incubated at the optimum incubation temperature.

Accordingly seed of the several varieties was planted January 5, 1923, in the cans in the same soil and with the same soil moisture as in Experiment 10. The cans were held in a greenhouse the mean temperature of which was 23.5°

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. 12.—*Influence of temperature on the development of Puccinia graminis tritici on wheat plants at the seedling stage*
Form IX

Experiment 11

ıty	Per cent of plants infected at						Degrees of infection at						Types of infection at					
	5°C.	10°C.	15°C.	20°C.	25°C.	30°C.	5°C.	10°C.	15°C.	20°C.	25°C.	30°C.	5°C.	10°C.	15°C.	20°C.	25°C.	30°C.
ub 4066	0	23	6	48	47	10	...	1	2–5	1–3	1–3	1	...	4	4	4	4	4
5146	0	0	0	0	0	0	...	...	...	...	...	...	...	...	...	...	...	...
ted 1558	0	5	26	0	6	5	...	1	1	...	1	1	...	3	3	...	4	4
1493	0	10	60	38	12	0	...	1–2	1–3	1–3	1	...	...	3–4	3–4	3	3	...
5296	0	0	0	0	0	10	...	...	...	...	...	1	...	...	...	...	...	X
1440	0	6	0	0	40	0	...	1	...	...	1	...	...	X	...	...	X	...
2433	0	4	5	0	0	6	...	1–2	1	...	...	1	...	3	3	...	...	4
4013	0	43	40	0	8	0	...	1–2	1–3	...	1	...	...	1	1	...	1	0

explanation of symbols used in this table see page 9.

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cases maintained at the temperatures of 5°, 10°, 15°, 20°, 25°, and 30°. A daily mean of 5.2 hours of sunshine prevailed during the course of the experiment.

The results at the conclusion of the experiment, February 9, 1923, are given in Table 12. It will be noted that practically the same results were obtained at 30° C. as in Experiment 10. Only a few plants of some varieties became infected with a trace of rust. At 15°, 20°, and 25° the results are, on the whole, similar to those obtained in Experiment 10. Some rust appeared in the 10° case, whereas in Experiment 10 no rust occurred. The development of rust at this temperature was very slow indeed, due both to the slow growth made by the plants and the low temperature for rust development. For example, uredinia were breaking thru on January 23 at 25° and 30°, on January 26 at 20°, on January 31 at 15°, and on February 5 at 10°. Up to that date no rust appeared at the temperature of 5°.

At the conclusion of the experiment, February 9, the plants held in the 5° C. case were removed to the cold room maintained at a temperature of 5° or below. On March 20, 9 weeks after inoculation, not one uredinium was observed on any of the plants. The plants were then transferred to a warm greenhouse and left for 6 days, after which time the plants were carefully examined and some plants were found infected, as follows: 2 plants of Turkey Red, 6 of Arnautka, 6 of Einkorn, and 3 of Khapli. The mean temperature of the greenhouse for this 6-day period was 23°.

Here we have an instance where seedlings were inoculated and incubated at 23° C. for 48 hours, and then held at a temperature of 5° or below for 9 weeks. At the conclusion of this period no rust was visible; but on transferring the plants to a mean temperature of 23° for 6 days, rust appeared.

An incubation temperature of 23° C. did not have any influence on the development of rust when the plants were subsequently grown at temperatures of 15° and above. How-

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INFLUENCE OF TEMPERATURE ON INFECTION AND DEVELOPMENT OF PUCCINIA GRAMINIS TRITICI ON WHEAT PLANTS AT THE STOOLING AND JOINTING STAGES FORM III

Experiment 12.—On January 4, 1922 the cans containing the plants of the differential hosts which had been growing in the greenhouse for the previous month were placed in the temperature cases maintained at 20°, 25°, and 30° C. The mean temperature of the greenhouse for the month was 24.2°. On January 24, the plants were inoculated by the spray method. A daily mean of 7.0 hours of sunshine prevailed during the period the plants were in the cases.

TABLE 13.—*Influence of temperature on infection and development of Puccinia graminis tritici on wheat plants at the stooling and jointing stages*

Form III

Experiment 12

Variety	Degrees of infection at			Types of infection at		
	20°C.	25°C.	30°C.	20°C.	25°C.	30°C.
Little Club C. I. No. 4066	5	5	1	4	4	4
Marquis C. I. No. 3641	5	4	1	4	4	4
Kanred C. I. No. 5146	5	4	1	4	4	4
Turkey Red C. I. No. 1558	5	4	1	4	4	4
Kota C. I. No. 6248	5	3	...	4	4	...
Kubanka C. I. No. 1440	2	3	...	X	X	...
Einkorn	3	3	...	3	3	...
Khapli C. I. No. 4013	2	4	1	1	1	0;–1

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On January 30, uredinia on some of the leaves were noted in the 25° and 30° C. cases, while 3 days later they began to appear on the plants in the 20° case. From this time on to the final reading, rust developed very rapidly. A summary of the results obtained is given in Table 13. It will be noted that only a trace of rust on some varieties occurred at 30°. Most of this rust was present on the lower leaves, with only an occasional secondary infection. Some telia were observed on several of the plants.

From a moderate to a considerable amount of rust developed at 25° C. Here 3 generations of rust were found, namely: the original infection with telia on the lower leaves, large pustules on the leaves half way up, and new pustules just appearing on the tip leaves. No stem infections were noted.

Rust was extremely abundant on all the plants at 20° C. Here also 3 generations of rust were present, and in addition some uredinia on the stems which were developing into telia. On the whole, a very high percentage of infection was obtained at 20° and 25°. These results are very similar to those obtained on seedling plants in Experiment 9.

INFLUENCE OF TEMPERATURE ON INFECTION AND DEVELOPMENT OF PUCCINIA GRAMINIS TRITICI ON WHEAT PLANTS AT THE STOOLING AND JOINTING STAGES FORM IX

Experiment 13.—As in the previous experiment, the cans containing plants of the differential hosts which had been growing in the greenhouse for about 2½ months were placed in the temperature cases held at the temperatures of 5°, 10°, 15°, 20°, 25°, and 30° C., on February 9, 1923. The mean temperature of the greenhouse for the 2½ months was 17.2°. Three days later they were inoculated by the dusting method. A daily mean of 7.4 hours of sunshine prevailed during the period the plants were in the cases.

Five days after inoculation, uredinia were observed on some of the plants in the 25° and 30° C. cases. A few days later they were noted on the plants in the 20° case. Rust was

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TABLE 14.—*Influence of temperature on infection and development of Puccinia graminis tritici on wheat plants at the stooling and jointing stages*

Form IX

Experiment 13

Variety	Degrees of infection at						Types of infection at					
	5°C.	10°C.	15°C.	20°C.	25°C.	30°C.	5°C.	10°C.	15°C.	20°C.	25°C.	30°C.
Little Club C. I. No. 4066	...	...	1	1	2	...	...	...	4	4	4	...
Kanred C. I. No. 5146	...	...	...	...	...	...	...	...	...	...	...	...
Turkey Red C. I. No. 1558	...	...	....	1	1–2	1	...	...	...	3	3–4	3
Arnautka C. I. No. 1493	...	...	1	1–3	2	1	...	...	4	4	4	3–4
Mindum C. I. No. 5296	...	...	...	...	1–3	1	...	...	...	...	X	X
Kubanka C. I. No. 1440	...	...	...	1	1–3	1	...	...	...	X	1	X
Einkorn C. I. No. 2433	...	...	...	...	...	...	...	...	...	...	...	...
Khapli C. I. No. 4013	...	...	...	...	1	...	...	...	...	...	1	...

Per cent of plants infected omitted owing to small number of plants.
For explanation of symbols used in this table see page 9.

while only a trace on 2 varieties was observed at 15°. Owing to the shortness of the period that the plants were held at these temperatures, only one generation of rust was present, which was strictly limited to the leaves. No telia were observed.

As no rust was observed on the plants in the 5° and 10° C. cases at the conclusion of the experiment almost 7 weeks after inoculation, the plants from the 5° case were set on a bench of the warm greenhouse for one week (mean temperature 23.0 C.). At the end of the week a trace of rust, with typical uredinia for the individual varieties respectively, was found on Little Club, Turkey Red, Arnautka, Kubanka, and Einkorn. Thus, as in Experiment 11, we have an instance of lengthened period incubation due to low temperature.

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INFLUENCE OF TEMPERATURE ON INFECTION AND DEVELOPMENT OF PUCCINIA GRAMINIS TRITICI ON WHEAT PLANTS AT THE HEADING STAGE

FORM III

Experiment 14.—On April 21, 1922, the cans containing the differential hosts which had been growing in the greenhouse since January 3 at a mean temperature of 17.8° C. were placed in the temperature cases of 20°, 25°, and 30°. Several days later they were inoculated by the dusting method. A daily mean of 8.0 hours of sunshine prevailed during the course of the experiment.

On April 27, a large number of ruptured uredinia were noted on the plants in the 25° C. case while only a few flecks appeared on the plants in the 20° case. At the conclusion of the experiment a heavy infection of the leaves was found

TABLE 15.—*Influence of temperature on infection and development of Puccinia graminis tritici on wheat plants at the heading stage*

Form III

Experiment 14

Variety	Degrees of infection at			Types of infection at		
	20°C.	25°C.	30°C.	20°C.	25°C.	30°C.
Little Club C. I. No. 4066	5	5	...	4	4	...
Marquis C. I. No. 3641	5	4	...	4	4	...
Kanred C. I. No. 5146	4	4	...	4	4	...
Turkey Red C. I. No. 1558	4	4	...	4	4	...
Kota C. I. No. 6248	2	3	...	3–4	4	...
Kubanka C. I. No. 1440	5	2	...	X	X	...
Einkorn	4	...	...	3–4	...	...
Khapli C. I. No. 4013	4	4	...	0;–1	0;–1	...

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on the plants held at 25°, as can be seen in Table 15. Stem infection was limited to the spring wheats. A much heavier infection occurred on the plants held at 20° (Pls. 9 to 12). Here stem infection on the spring wheats was common and quite severe. In the 30° case, no rust was observed on any of the plants at any time during the course of the experiment.

INFLUENCE OF TEMPERATURE ON INFECTION AND DEVELOPMENT OF PUCCINIA GRAMINIS TRITICI ON WHEAT PLANTS AT THE HEADING STAGE. FORM IX

Experiment 15.—As in the previous experiment, the plants were held in the greenhouse from November 28, 1922, to March 30, 1923, at a mean temperature of 17.8° C. and then transferred to the temperature cases maintained at 10°, 15°, 20°, 25°, and 30°. Several days after the plants had been placed in the cases, they were inoculated by the dusting method. A daily mean of 9.0 hours of sunshine prevailed during the course of the experiment. The results of the experiment are given in Table 16.

TABLE 16.—*Influence of temperature on infection and development of Puccinia graminis tritici on wheat plants at the heading stage*

Form IX

Experiment 15

Variety	Degrees of infection at					Types of infection a				
	10°C.	15°C.	20°C.	25°C.	30°C.	10°C.	15°C.	20°C.	25°C.	30°C.
Little Club C. I. No. 4066	4	4	2	2	...	4	4	4	4	...
Kanred C. I. No. 5146	...	...	...	...	...	...	...	...	...	...
Turkey Red C. I. No. 1558	...	1	...	...	...	...	3	...	...	...
Arnautka C. I. No. 1493	4	4	2	1	...	4	4	4	3–4	...
Mindum C. I. No. 5296	...	4	1	1	...	...	X	X	X	...
Kubanka C. I. No. 1440	4	4	2	2	...	X	X	X	X	...
Einkorn C. I. No. 2433	...	...	...	...	...	...	...	...	...	...

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Rust was observed on the inoculated plants held at the various temperatures as follows: at 25° C. after 6 days, at 20° after 8 days, at 15° after 12 days, and at 10° after 20 days. No rust at all was observed during the course of the experiment at 30°, while only a sprinkling of rust occurred at 25°. A heavier infection occurred at 10° and 15° than at 20°. The failure of the winter wheat varieties to become infected can be explained thru the fact that they were completely shaded by the spring wheat varieties, which were headed and much taller. In fact, these varieties all made a rather poor growth owing to this condition. At 10°, rust pustules were present on the leaves, sheaths, and an occasional stem and glume. At 15°, more rust occurred on the stems than at 10°, while at 20° only 2 varieties had stems infected and only one at 25°.

Judging from the results obtained in Experiment 15, infection and the subsequent development of rust appears to be more favored by low temperatures. This may be due in part to the unfavorable temperature preventing the normal development of the plants at temperatures of 25° and higher.

INFLUENCE OF LOW TEMPERATURE ON THE PERIOD OF INCUBATION OF PUCCINIA GRAMINIS TRITICI ON TURKEY RED SEEDLINGS FORM IX

Experiment 16.—In Experiment 11, it was found that seedling plants, when inoculated and incubated for 48 hours at 23° C., did not produce any visible signs of infection over a period of 9 weeks, if the plants were thereafter kept at a temperature of 5°. However, when the plants were transferred to a temperature of 23° uredinia developed on some of the plants within a week.

Further in Experiment 13, it was shown that plants at the stooling stage, inoculated, incubated, and held at 5° C., pro-

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TABLE 17.—*Influence of low temperature on the period of incubation of Puccinia graminis tritici on Turkey Red seedlings*

Form IX

Experiment 16

Number of weeks from time of inoculation plants were kept in cold house	Set I		Set II		Set III	
	Per cent of plants infected	Number of uredinia per leaf	Per cent of plants infected	Number of uredinia per leaf	Per cent of plants infected	Number of uredinia per leaf
1	27	1–4	13	1–2	7	1
2	53	1–2	7	2	20	1
3	27	1	20	1	13	2
4	47	1	27	1	0	0
5	47	1–3	20*	2	27*	1–3
6	33	1–10	7	1	0	0
7	33	1	13*	1–2	20§	1
8	40*	1–5	20§	1–10	20§	1
9	13*	1	33§	1	13§	1
10	53§	1	7§	1	27§	1

*One or two pustules visible when taken out of cold house.
§All pustules visible when taken out of cold house.

incubation the plants were divided into 3 sets and treated as follows:

Set I. Plants placed in the cold house immediately after incubation.

Set II. Plants benched in the warm house for 3 days and then transferred to the cold house.

Set III. Plants benched in the warm house for 5 days and then transferred to the cold house.

During the course of the experiment a temperature of 5° C. and below was maintained in the cold house. Occasionally the temperature dropped to freezing or slightly below.

At the end of every week, 3 pots of 6 plants each were withdrawn from each set in the cold house and placed on the bench in the warm house for one week, when the number of plants infected and the number of uredinia were noted.

To determine the host-parasite relation in the tissues of the plants, one or two leaves from plants of each set were fixed in Fleming weak solution every week when the plants were withdrawn from the cold house. A study of this material should determine in what form the parasite remains in the tissues during the dormant period of incubation.

The results of the experiment are tabulated in Table 17. It will be noted that in Set I a fairly uniform number of plants developed uredinia each week, after their transfer to a warm house. It was not until the eighth week that any pustules

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were found on the plants in Set I in the cold house. After the tenth week the experiment was closed because uredinia were visible on some of the leaves of the plants in the cold house. In Set II a few pustules were visible on the plants in the cold house after 5 weeks and in a week or two more the pustules appeared on the majority of the infected plants. The same was true of the plants in Set III.

It must be borne in mind that before the plants were divided into the 3 lots, they were all inoculated in the same way; and had they been divided and then placed at a warm temperature, no doubt the percentage of infection would have been about the same. However, after the plants in Set I were transferred each week to the warm house an average of 38.7 per cent developed rust, while only 16.7 per cent and 14.7 per cent respectively were obtained in Sets II and III. In other words, the plants placed in the cold house immediately after 48 hours incubation produced a larger percentage of infection than the plants in which the parasite was further developed. Not only were a larger number of plants infected in Set I but a larger average number of pustules was obtained as contrasted with Set II and Set III. A low temperature apparently did not affect the viability of the parasite in the tissues of the leaves in Set I, owing to its undeveloped state; while where the parasite was further developed, as in the case of the infected plants in Set II and Set III, the low temperature did influence the viability of the parasite as judged by the number of plants infected and by the amount of rust which developed after they were transferred to the warm house.

After the experiment was discontinued, there remained a large number of plants in all 3 sets in the cold house. A

TABLE 18.—*Influence of low temperature on the period of incubation of Puccinia graminis tritici on Turkey Red seedlings*

Form IX

Experiment 16

	Set I	Set II	Set III

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count of the number of plants infected with the number of pustules per leaf was made for each set, and then all plants were placed on a bench in the warm house for 1 week, after which another count was made. The results are listed in Table 18.

No increase in the number of plants infected was noted on the plants in Set III. A 3 per cent increase was obtained on the plants in Set II and 10 per cent in the case of Set I. It will also be noted that the number of pustules per leaf is largest on the infected plants in Set I. The results again substantiate the statement made above in regard to the stage of development of the parasite in the tissues and its viability at low temperatures.

We may conclude from the results obtained that the period of incubation of stem rust can be extended over a long period by subjecting the inoculated plants to a temperature of 5° C. and that the length of this period depends upon the stage of development of the organism inside the tissue of the plant. These results are suggestive of the way overwintering might be successful under field conditions in certain localities of the winter wheat belt.

COMPARISON OF THE TYPES OF INFECTION OBTAINED WITH THE RESULTS OF OTHER INVESTIGATORS

As has been stated before, in no instance was the type of infection altered by any environmental factor or factors employed. The reaction of the biologic form to a definite host was always the same within certain limits. The results agree, with few exceptions, with those worked out by Stakman and Levine[1] and these exceptions are of minor importance.

During the work with Form III, the results checked with those of Stakman and Levine on all the differential hosts but two. Stakman and Levine using a Minnesota selection Kubanka (C. I. No. 2094) report a range of infection on this host from 0 to 2 with a mean of 1+ when infected with Form III. In our investigation Kubanka C. I. No. 1440 was employed most frequently but instead of obtaining a reaction similar to Stakman and Levine's there developed in all cases a heterogeneous type of infection. Furthermore, on using various Cereal Investigations numbers of Kubanka including C. I. No. 2094, the same results were obtained. Similarly with Speltz Marz, Stakman and Levine reported a range of infec-

[1] Loc. cit.

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tion between 0 and 1 + + with a mean of 1 = with Form III, whereas we obtained a mean of 3. However, neither the Cereal Investigations accession number nor the original source of the seed of this differential host was known, so that we cannot draw any comparisons.

Again, with Form IX, Kubanka reacted similarly, and a heterogeneous type of infection was obtained irrespective of the Cereal Investigations number used or the locality from which the seed was obtained. Stakman and Levine's results show that their Kubanka (C. I. No. 2094) has a type of infection of 4. Mindum also produced a heterogeneous type of infection with Form IX instead of type 4 as reported by Stakman and Levine. The latter have used a pure line selection of Mindum (Minn. No. 470), the original seed having been obtained from the Section of Plant Breeding of the Minnesota Agricultural Experiment Station.

Owing to the fact that only one form of rust was introduced into the greenhouse each season, the results obtained cannot be attributed to a mixture of forms. They may perhaps be explained by the fact that the stock material furnished the writer by Dr. Stakman and Mr. Levine was not from the original isolation which was used by them to make their test, but from a reisolation obtained in the field at another time. However, these variations in results are of minor importance.

From the results obtained, we can conclude that under the environmental conditions to which both the host and the parasite have been subjected the type of infection remained constant and that, with the minor exceptions noted above they are in complete accord with those obtained by Stakman and Levine. By "constant" the writer does not mean that the types of infection are fixed within narrow lines but that a resistant plant never becomes susceptible or vice versa. Or, stated in another way, a differential host may react to a biologic form within a range of from 0 to 2, or 3 to 4, but never from 0 to 3, or 1 to 4, or even 2 to 3.

DISCUSSION

While one of the aims of the present investigation was to determine whether the 2 biologic forms of *Puccinia graminis tritici* studied remained constant under various environmental conditions, it is only one phase of a study of the environmental conditions influencing the development of stem rust in the absence of an alternate host. It is essential that a

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study be made of the environmental factors influencing, not only the growth of the host plants at various stages of growth, but also infection and the development of the disease, to determine under what environmental conditions in the field the red spore stage could propagate itself from season to season in the absence of the common barberry, in view of the fact that the barberry is being eradicated in the grain growing states of the Middle West. Since the results of all the experiments showed conclusively that the types of infection cannot be radically changed by the conditions to which the host and parasite are submitted, the discussion of the influence of environmental factors on the growth of the host plant and on infection and development of the disease will be taken up.

During the course of the investigation wheat plants at the seedling, stooling, jointing, and heading stages have been studied. It has been shown that with temperatures of 25° C. and below, the per cent of germination was the same provided the time element was considered. As far as could be determined from the limited population used, seed of all the differential hosts germinated about equally well at all these temperatures. A soil and air temperature of 30° in all instances decreased the per cent of germination of all the differential hosts employed. This was especially true of Kanred and Turkey Red.

For the best development of the seedlings subsequent to germination and emergence, the optimum temperatures appeared to be at 15° and 20° C. Temperatures of 25° and 30° were too high and their influence on the seedlings resulted in an excessive elongated mesocotyl. A good growth was obtained at 5° and 10° but it was extremely slow.

Similarly at the stooling, jointing, and heading stages the best development of the plants occurred at 15° and 20° C A temperature of 30° produced stunted plants and seemed to inhibit both stooling and heading. At 25° stooling was inhibited, but this temperature favored the more rapid heading of the plants. Until more data have been obtained on the influence of not only temperature but other environmental factors as well on the development of wheat plants at different stages of growth, no attempt will be made to correlate the results of greenhouse studies with what occurs under field conditions.

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The conditions essential for the successful infection of wheat plants by urediniospores are a suitable temperature free moisture or a very high relative humidity, and an actively growing plant. In speaking of infection, one must distinguish between the period of initial infection and the period of incubation. The writer[1] has defined these periods as follows: "By the period of initial infection is meant the time required by the organism after it reaches a leaf, to enter the stomata or, in case of wounds, the tissue of the plant. The period of incubation, on the other hand, is the period extending from initial infection until the disease is visible."

The object of the first 4 experiments was to determine the temperature suitable for initial infection. The optimum temperature for initial infection for Form III appeared to be 25° C., while in the case of Form IX it is nearer 20°. A much higher percentage of infection was obtained with Form III at 30° than with Form IX. However, the lower temperatures appeared to be more favorable for initial infection for Form IX than for Form III. In other words, the range of temperatures suitable for initial infection by Form IX was about 5° lower than for Form III. The various incubation temperatures employed influenced not only initial infection but also the period of incubation, in that the lower incubation temperatures retarded the period of incubation.

Seedling plants grown at the various temperatures, inoculated and held at these same temperatures until the conclusion of the experiment, yielded quite different results. No infection was obtained at 10° C. and below. Only a few plants of some differential hosts were infected at 15° and 30° The optimum temperatures for infection in these experiments were between 20° and 25° for both forms. The period of incubation varied with the temperature, being shortest at 30° and longest at 15°.

Similarly plants at the stooling and jointing stages became most heavily infected with rust at 20° and 25° C. No infection was obtained at 5° and 10°. Only an occasional plant was infected with a trace of rust at 15° and 30°.

Plants at the heading stage seemed to have a lower

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was produced at 25° as at 20°, while the plants inoculated with Form IX were most heavily infected at 15°. As in former experiments, the period of incubation was shortest at the high temperatures and longest at the lower temperatures.

In conclusion, it might be stated in a general way that there is a wider temperature range for infection of seedling plants by rust than of plants in the heading stage. This is especially true of the higher temperatures. The temperatures at which the plants make their best growth are generally the most favorable for the best development of the disease.

In Experiment 11, seedling plants were inoculated and incubated at the optimum temperature for initial infection and after incubation placed at the various temperatures. As has been pointed out, no material differences were noted at temperatures of 15° C. and above, on the period of incubation. However, plants held at 5° for 9 weeks did not develop any rust until they were transferred to a higher temperature. On the other hand, the incubation period of the rust on plants placed in the 10°, 15°, 20°, 25°, and 30° cases was 18, 16, 11, 8, and 8 days respectively. In this instance we had a lengthened period of incubation, due solely to a low temperature which slows down the normal functions of the host and parasite. However, immediately upon the speeding up of the plant functions by their transfer to a higher temperature, the parasite also becomes active. Perhaps under suitable conditions the period of incubation could be lengthened over a period of several months.

In Experiment 13, plants inoculated at 5° C. and maintained at this temperature for 7 weeks developed no rust until they were transferred to a higher temperature. In this instance the question naturally arises whether initial infection can take place at 5°, as we have no direct evidence that the urediniospores can germinate and enter the host plant at this temperature. The writer[1] obtained similar results in his Citrus canker investigation in that Citrus plants inoculated at the temperatures of 5°, 10°, and 15° produced no signs of infection until they were transferred to a higher temperature.

Experiment 14 was carried out to supplement the results obtained in Experiment 11. The results showed that a rather uniform number of plants that immediately after incubation

[1] Loc. cit.

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were placed at a low temperature, developed rust each week when brought out of the cold house. No rust was visible on these plants in the cold house until the eighth week. Plants of the other 2 sets when brought out of the cold house did not produce as high an average per cent of infection, nor as many uredinia on the plants as in Set I.

From the results of all these experiments there can be no question but that the period of incubation of stem rust can be extended over a long period at a low temperature. The length of this period depends not only upon the temperature but also on the stage of development of the organism in the leaf tissues of the host. These results are very suggestive of the way overwintering of the uredinial stage might occur in some localities of the winter wheat belt.

Initial infection can take place under conditions which do not favor the development of the disease. Furthermore, it may occur and the organism remain quiescent in the tissues for long periods without any signs of the disease being manifested. In fact, we may assume that there are occasions when initial infection takes place without the subsequent development of the disease, because of unfavorable external and internal conditions for its development. Thus, initial infection requires a definite set of conditions entirely different from those required for the development of the organism after it enters the host plant. About the same conclusions were drawn in the writer's investigations [1] of the influence of temperature on infection and development of Citrus canker caused by a bacterium.

In presenting the experimental data, the writer has referred to the influence of sunshine on the per cent of infection and amount of rust. It will also be noted that under each experiment the total or the daily mean hours of actual

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When the hours of sunshine were greater, other factors being equal, a higher percentage of infection and a larger number of uredinia per leaf resulted. Thus, we do have an indirect influence on the parasite, thru the better growing conditions of the host. The writer does not know whether it is the duration or the intensity of sunshine, or both, that enhances this relation, altho from the observations which have been made, it appears that duration of sunshine is more important than intensity.

For some reason, Form IX did not have the ability to infect the differential hosts as readily as Form III. This was noticeable in all the experiments but one, where the per cent and degrees of infection are given. In this one experiment (Number 8) the per cent and degrees of infection are on the average as high or higher than those obtained with Form III. However, it will be noted that during the course of the experiment 53.8 hours more of sunshine prevailed than during the period of Experiment 7. In all the other experiments where Form IX was used, the total or daily mean hours of sunshine was less than in the experiments where Form III was used. Whether we can correlate the evident differences between the infecting power of these 2 forms solely because a smaller number of hours of sunshine prevailed could not be determined, but there was no question but that fewer hours of sunshine may have played some part.

So far as the observations of the writer went, there was no evident difference between the resistant and the susceptible varieties in the length of time from initial infection until flecking appeared on the plants. However, unruptured pustules generally developed in a shorter period of time on the susceptible plants than on the resistant varieties.

At first thought one would suppose that, as a whole, the percentage and degrees of infection would be higher on the susceptible hosts than on those which were resistant. However, such is not always the case. A comparison of results obtained with Form III and Form IX, on Kanred, Arnautka, and Emmer and others show that, irrespective of whether they were susceptible or resistant to these forms, the percentage and degrees of infection are about the same when the other factors which enter in are considered.

Further, Khapli is considered the most resistant of the differential hosts to the 37 biologic forms of *Puccinia graminis tritici*. Still, if the average percentage of infected plants and degrees of infection are totaled for all the experiments,

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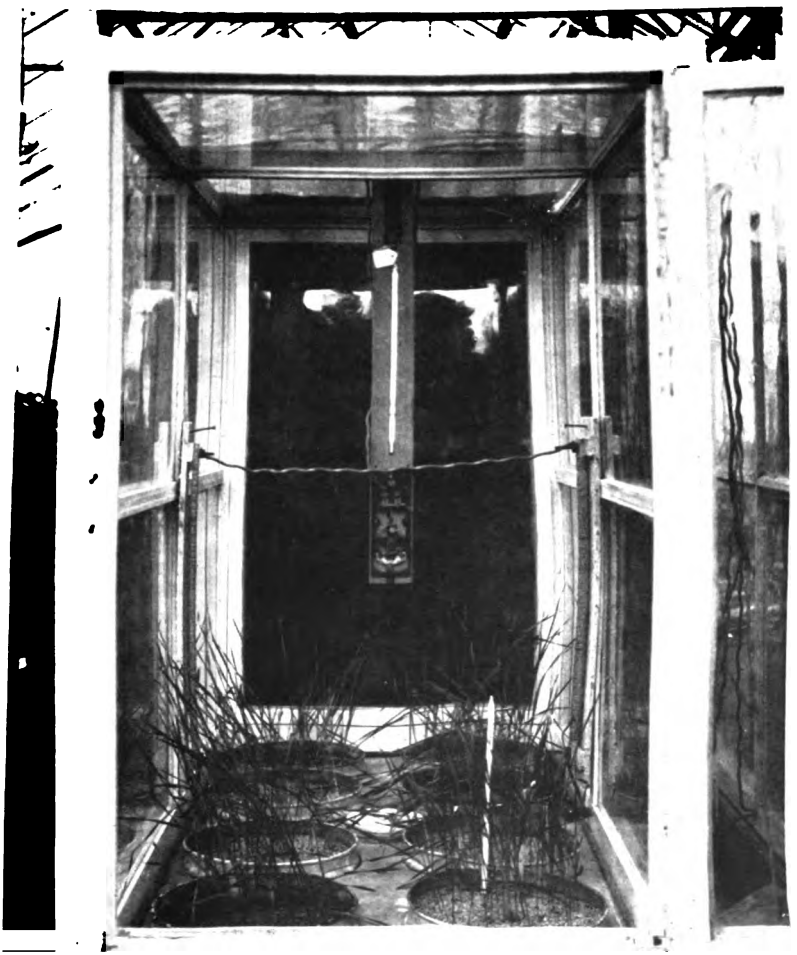
PLATE 1



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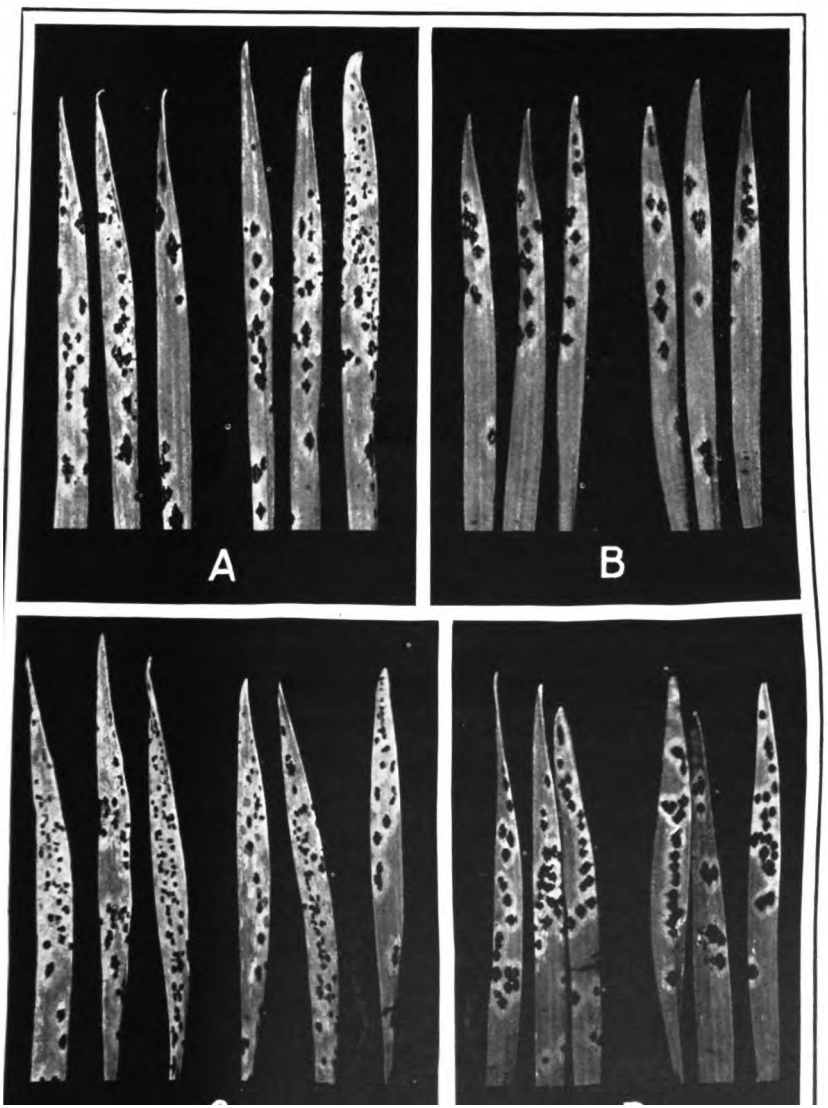

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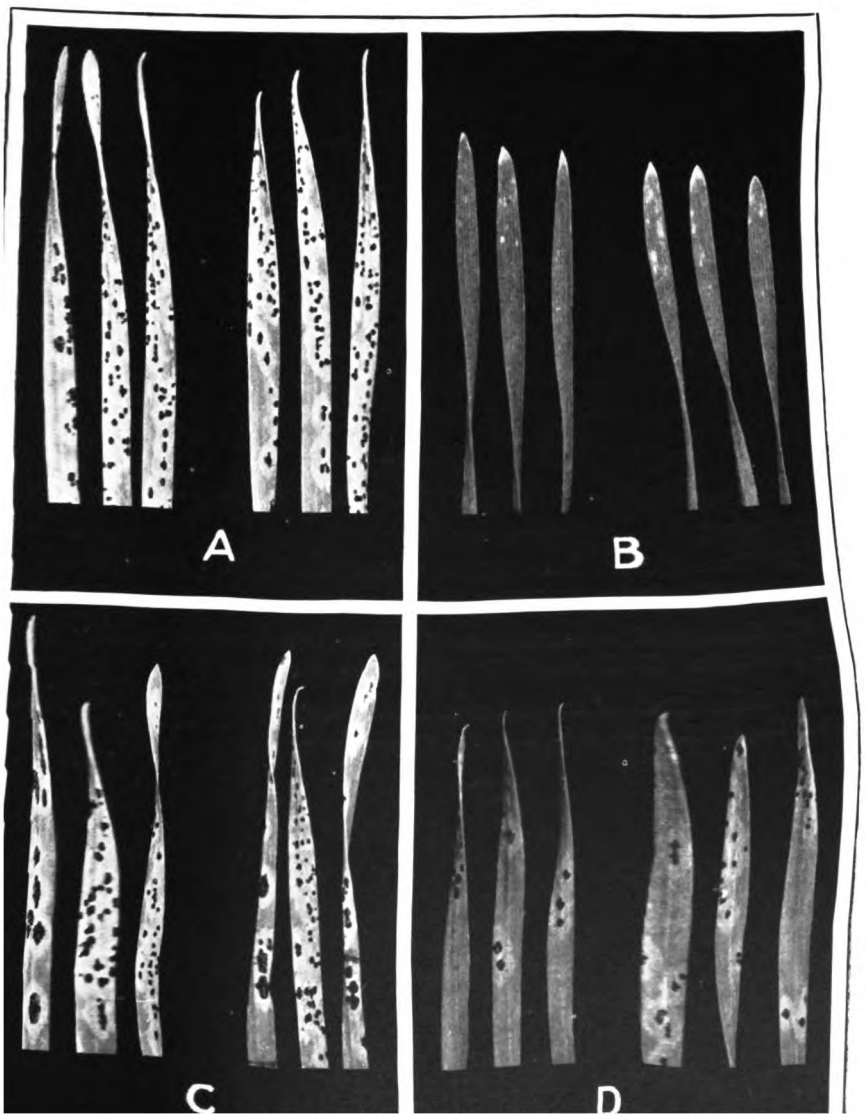

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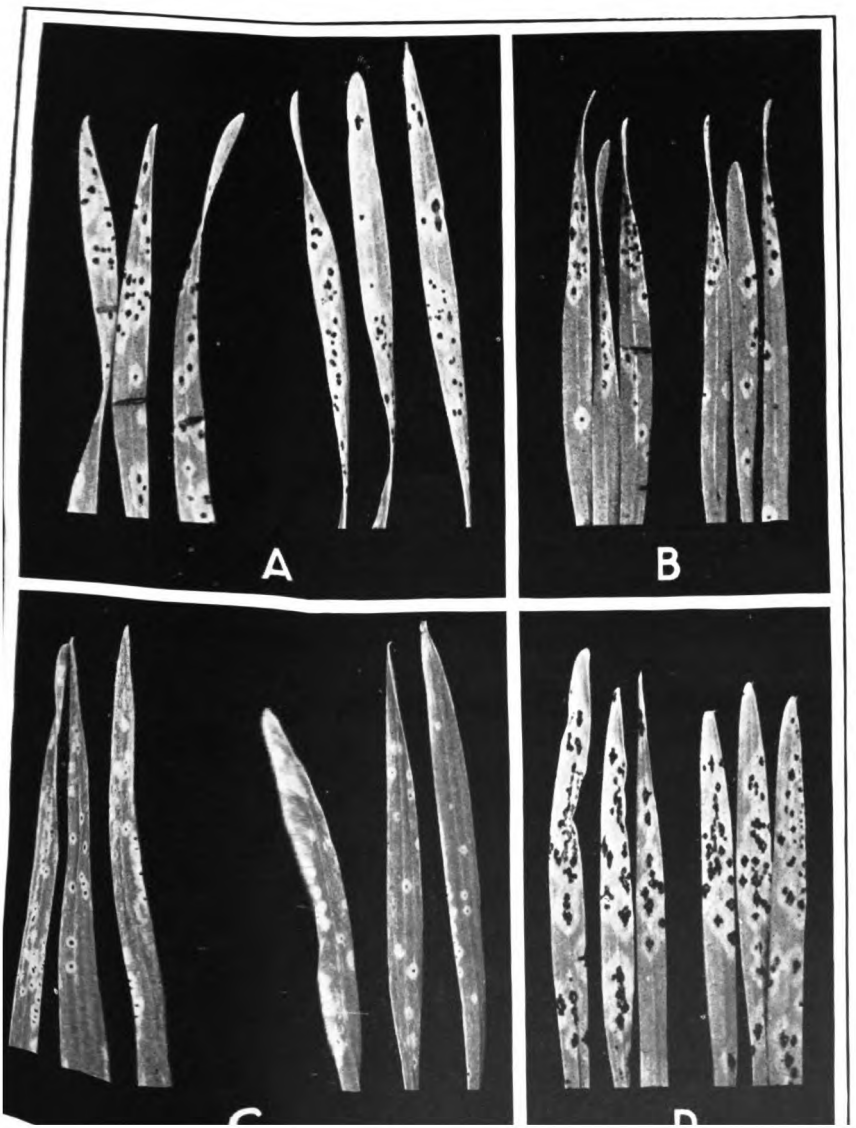

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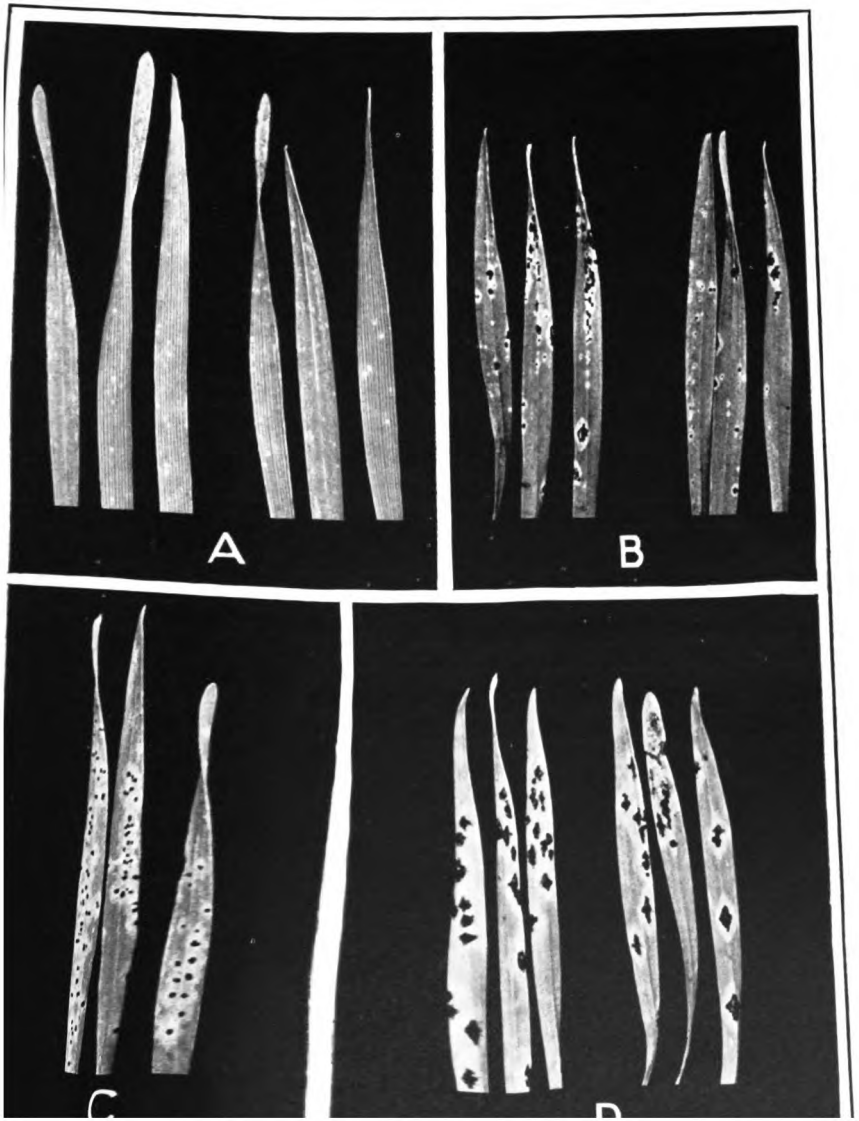

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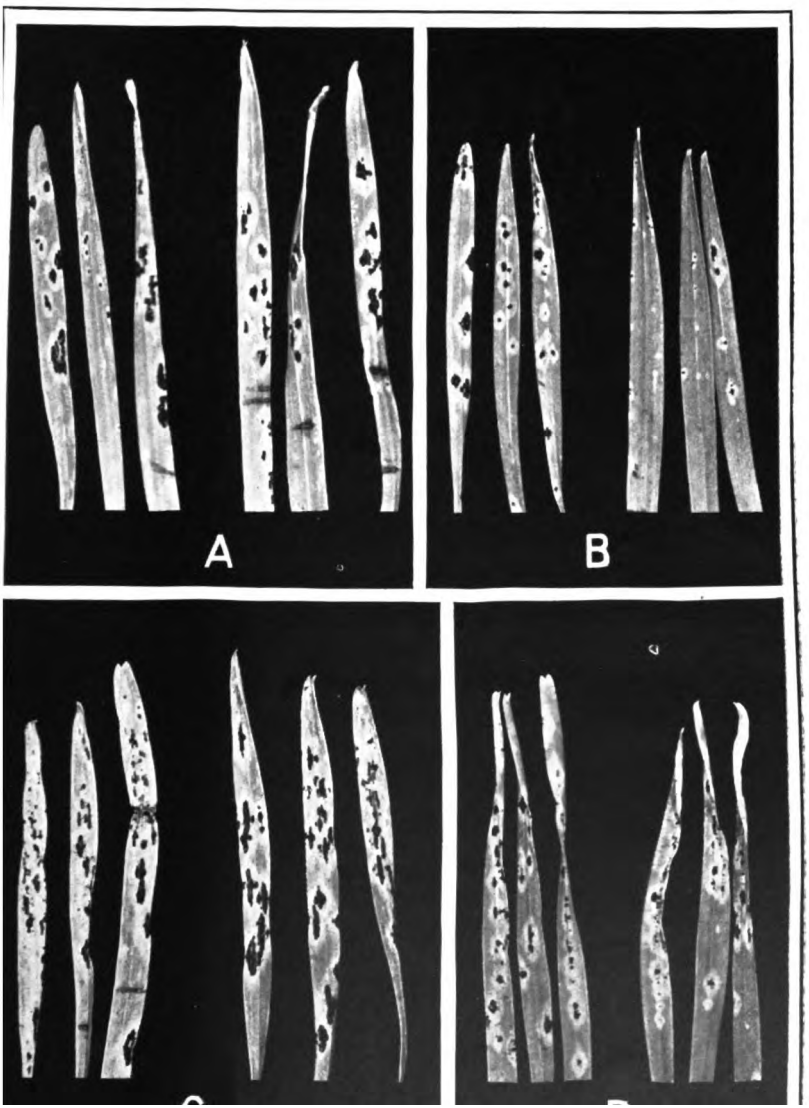

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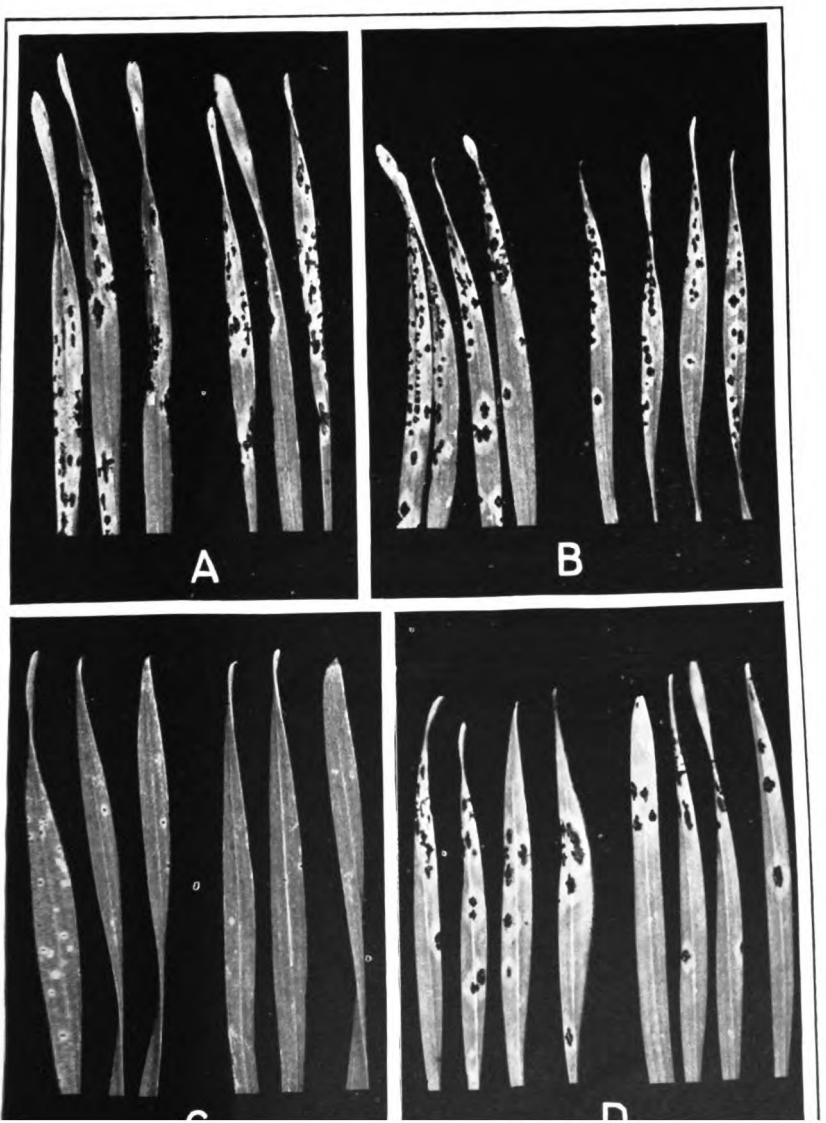

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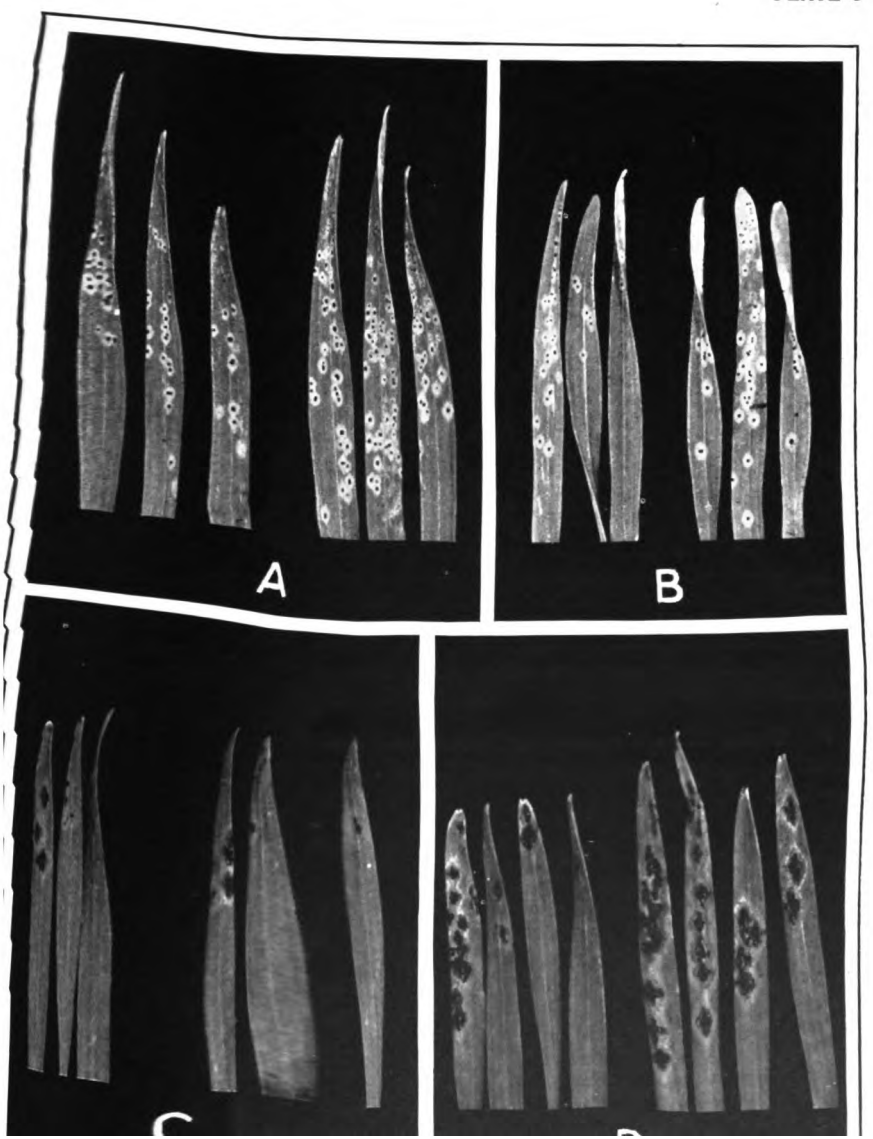

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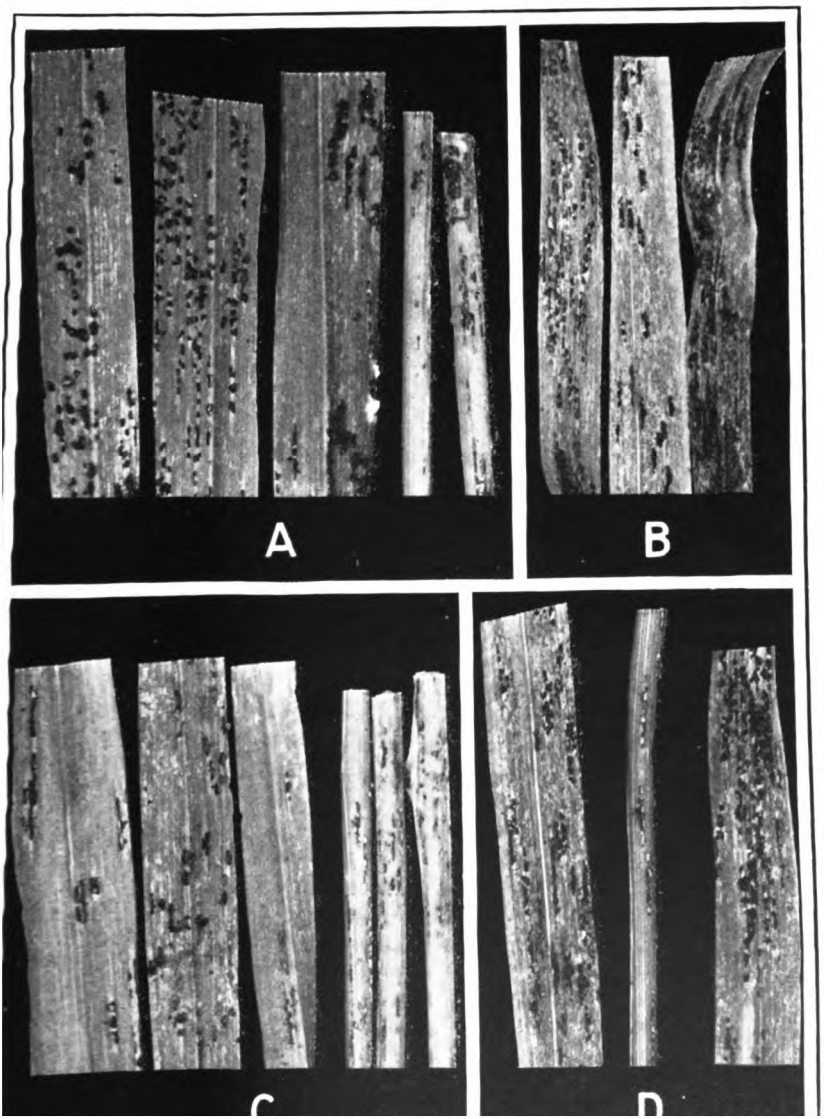

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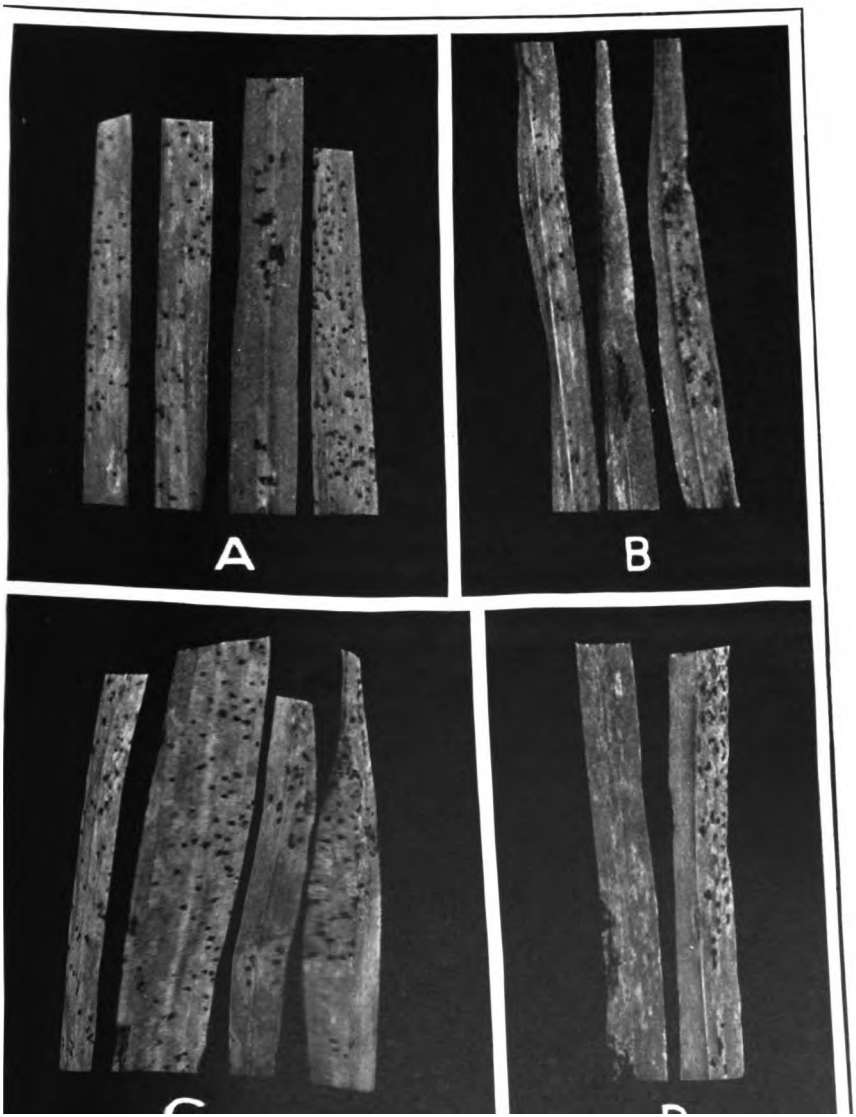

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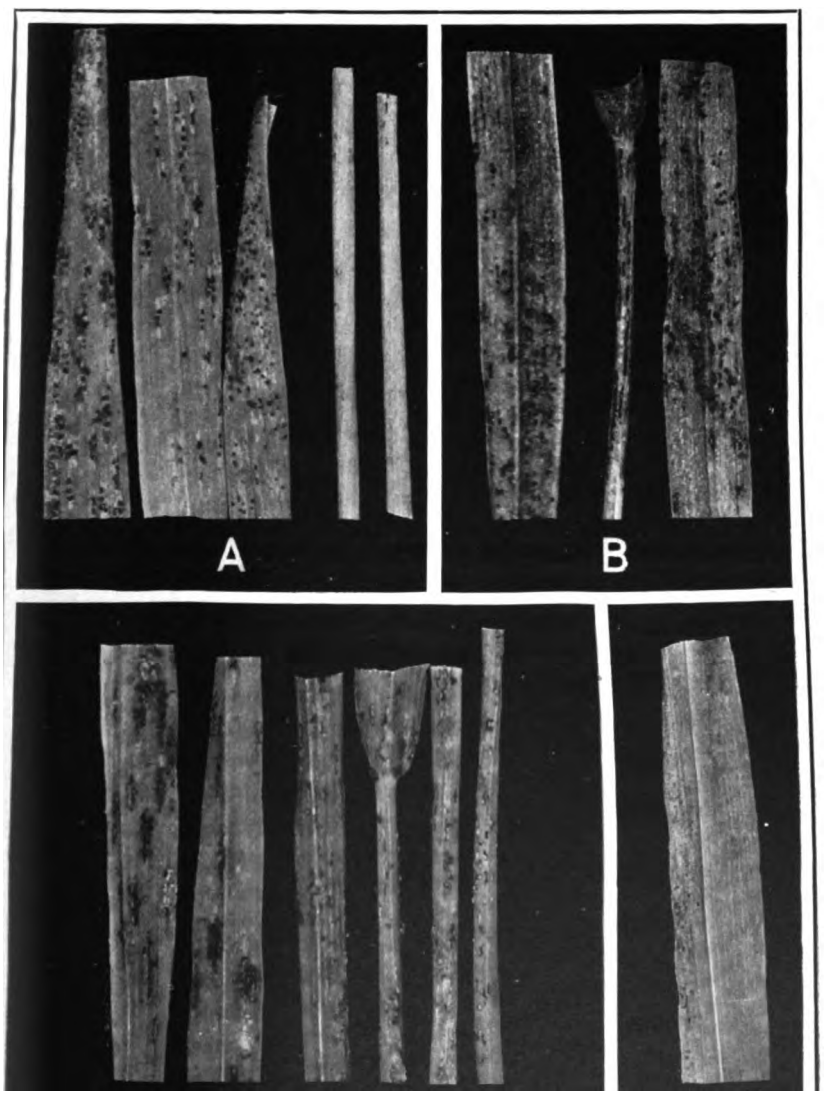
PLATE 11



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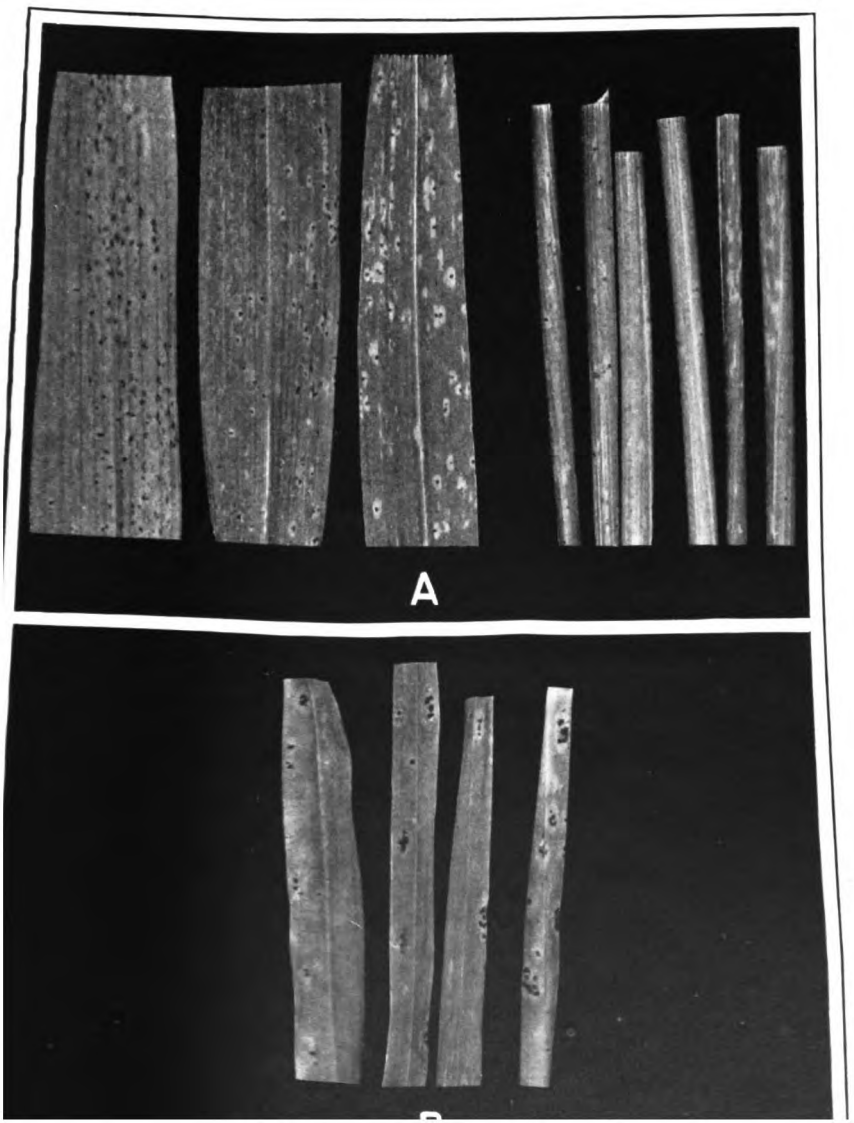

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COLLEGE OF AGRICULTURE UNIVERSITY OF NEBRASKA
AGRICULTURAL EXPERIMENT STATION
RESEARCH BULLETIN 26

Effect of Environment on Potato Degeneration Diseases

R. W. GOSS

DEPARTMENT OF PLANT PATHOLOGY

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SUMMARY

1. The symptoms of potato mosaic in the Bliss Triumph variety are influenced to a great degree by environmental conditions.

2. Temperatures above 70° F. tend to decrease the number and severity of the symptoms, while temperatures below that point increase their visibility.

3. Mottling was found to be the most constant symptom when temperature alone was varied. High temperature with intense sunlight caused the disappearance of this symptom.

4. Wrinkling, curling, and rugosity were eliminated at the higher temperatures on mild mosaic plants.

5. High temperature is a greater factor in masking mosaic symptoms than low moisture or increased sunlight, altho under field conditions all 3 usually occur together.

6. The symptoms of mild mosaic reacted more quickly to environmental factors than the more severe types and the combinations of mosaic and spindle-tuber used in these experiments.

7. The effect of the environment on the symptoms decreased with the increasing age of the plant.

8. Under field conditions mosaic was more severe with early planting while spindle-tuber was more severe in the late plantings.

9. Short periods of 4 to 8 days of high temperature and increased sunlight were found sufficient to eliminate the leaf symptoms of mild mosaic and to decrease those of the more severe types.

10. The symptoms of mild mosaic under certain conditions appeared more serious than the symptoms of the more severe types of mosaic appeared under other conditions that were less favorable for the manifestations of the symptoms.

11. Climatic conditions as noted above can be correlated in commercial fields with:

(a) Changes in the appearance of the symptoms on the plants during the same season.

(b) Changes in the amount of visible mosaic in the same region for different seasons.

(c) Changes in the amount of mosaic found in northern grown seed from Nebraska when planted in the southern states.

12. In view of the data presented in this paper, the author believes

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Effect of Environment on Potato Degeneration Diseases

R. W. GOSS
DEPARTMENT OF PLANT PATHOLOGY

INTRODUCTION

During recent years much of the investigational work on the degeneration diseases of the potato has been directed toward the separation and identification of a number of diseases formerly grouped under the general names of mosaic, leaf roll, and "running out". Extensive studies have also been made on methods of transmission, host range, overwintering and the identification of the evasive causal factor.

Investigations of this type, however, have progressed slowly because of the necessity of developing new methods of research, because of the complexity of the problem, and because of the lack of knowledge regarding the causal factors. Meanwhile there is an immediate and pressing demand from the seed growers and the inspectors of certified seed for advice and instruction regarding these diseases. Their chief interest is in the problems of (1) the recognition of these diseases in the field, (2) their effects upon yield rate, and (3) methods of control. It seems, therefore, desirable to present here the results of certain preliminary studies which contribute in some measure to a better understanding of these more practical problems and to point out some of the factors, and their effects, which must be considered in a study of these problems.

CONSIDERATION OF THE PROBLEM

In discussing the 3 problems outlined above, emphasis will be laid upon the first, *i. e.*, the recognition of these diseases in the field. This is prerequisite to a proper investigation of the other 2 problems.

The symptoms of mosaic and related diseases have been known in a general way for a number of years. The recent publications on the subject, however, have caused a temporary confusion in the minds of workers not specializing on these diseases, but it is hoped they will eventually lead to a clearer understanding of the problem. The confusion, however, is nevertheless present. Quanjer (1921) (1923) describes from 6 to 8 different degeneration diseases occurring in Europe, Murphy (1921-B) lists 6 diseases of this type, and Schultz and Folsom (1923,

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p. 61) distinguish 7 diseases occurring on the Green Mountain variety. They also note that combinations of these diseases may occur, thus increasing the complexity of the problem. When we consider that these authors were working with different varieties, under different conditions, and often used different terms to describe similar symptoms, the reason for the resultant confusion is obvious. Schultz and Folsom (1923) give a very clear definition of the symptoms used in their descriptions. This should result in materially increased clarity of description in American papers. Their terminology will be used thruout this paper.

Schultz and Folsom (1920) (1923) demonstrated the possibility both of intervarietal transmission of certain degeneration diseases and of varietal modification of symptoms. However, the problem of varietal manifestations of these diseases is still largely unsolved.

The other factor to be considered, that of the effect of environment on the disease symptoms, has already received considerable attention. The masking of symptoms has been observed by numerous workers. Most of the statements in the literature, however, regarding this phenomenon have been based on general observations; and often where experimental evidence is presented, detailed data regarding the environmental factors are lacking.

The only experimental evidence secured under controlled conditions with which the author is acquainted was presented by Johnson (1922). He found the optimum temperature for the appearance of the symptoms to be between 14° and 18° C. "Above 20° C. symptoms disappear, the rate of recovery from the disease being increased in proportion to increase of temperature within the limits of host development. To completely inhibit the disease, however, within a period of one to two weeks, a temperature of 24° to 25° C. is necessary; and this may be regarded as the maximum temperature for mosaic manifestation in the potato. New leaves, free from symptoms, appear quickly at this temperature, and older leaves gradually lose their symptoms, the rate of 'recovery' being roughly proportional to the age of the leaf." He does not state the type of mosaic or the severity of the symptoms on the plants with which he was working, or the variety of potatoes used, nor does he mention soil moisture or sunlight, altho it is to be assumed that they were kept similar in the parallel tests.

Schultz, *et al.* (1919, p. 250) report that parallel plantings in Maine and Colorado showed an absence of mottling in Colorado and distinct mottling in Maine. Plantings in Maine and at

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Washington, D. C., gave somewhat similar results. Plantings made for 3 successive seasons in northeastern and southwestern Maine showed mottling to be inhibited in southwestern Maine, and the return of the progeny to northeastern Maine resulted in the reappearance of mottling. No data are given concerning the environmental factors of these different localities or the type of mosaic being studied. Schultz and Folsom (1923, p. 99-102) report a number of experiments in which the symptoms of these diseases were affected by climatic conditions. They found that mottling was particularly masked on mild mosaic plants when grown in Virginia in comparison with Maine and Long Island plantings. In greenhouse experiments they found wrinkling and mottling to be more marked at 16° than at 24° C. and that the transference of the plants from the high to the low temperature increased the symptoms on the new foliage. They found mottling to be more distinct on caged than on uncaged plants in the field. In other experiments with various types of mosaic, they report that a reduction in sunlight decreased the apparent dwarfing and increased mottling. In fertilizer experiments they found a decrease in the percentage of mosaic and in the distinctness of mottling, during the first part of the season, by high nitrogen and potash fertilizers. In none of this work, except in the greenhouse experiments, do the authors present very detailed information regarding temperature, moisture, and sunlight (aside from shading in insect cages) occurring in their experiments. They do not report, with the exception of the one experiment in Colorado, a change from distinct mottling to an absence of mottling. They find that a difference in climatic conditions results chiefly in a difference in the distinctness of the mottling, but that the stage or type of mosaic remains the same.

Ducomet (1923) in a recent paper discusses the influence of environment on the symptoms. He lays great stress upon moisture as well as temperature, and correlates the appearance of mosaic with wet seasons or with local wet regions in dry seasons. From his greenhouse experiments conducted at 12°-15° and 17°-22° C., some of the plants being under cloth, he concludes that "basses temperatures et air sec favorisent les deformations; temperatures élevées et air humide favorisent la maculature." It is to be noted, however, that his high temperatures were not as high as the temperatures employed by Johnson (1922), nor as high as the temperatures often occurring in the field in Nebraska. He found the disease to be more evident under cloth. He does not give any detailed data on temperature or moisture in his field observations.

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Murphy (1921) observes that, "a high temperature and favorable conditions for quick growth early in the season reduce the symptoms of mosaic." He notes that a mean temperature of 71.1° F. during June at Ottawa resulted in the suppression of the symptoms of mosaic, while in the previous year, with a mean temperature of 61.8° F., the disease was severe. He shows that the symptoms of the disease were masked under certain conditions, but that the plants remained a source of infection for neighboring healthy plants. The symptoms reappeared when tubers from these plants were grown the following year under more favorable conditions for the appearance of the disease. He finds that early planting favors the appearance of mosaic. The same author (1923) considers that moisture as well as temperature may influence the appearance of the disease.

In considering the second question, *i. e.*, the effect of these diseases on yield, no attempt will be made to review all the literature. Numerous investigators have reported variable decreases in yield as being due to these diseases. A few points in relation to this phase should be considered here, however.

The effect of locality on yield rate in relation to these diseases is of considerable importance. Schultz and Folsom (1923) report that an all-mosaic condition reduced the yield rate of Green Mountains more on Long Island than in northeastern Maine. Murphy (1921) reports that plants in which the symptoms of mosaic were masked gave practically as good yields as neighboring healthy plants. Data presented by Edgerton and Tiebout (1921) and other unpublished data obtained on Nebraska grown seed in Louisiana, show a much greater decrease in yield, due apparently to mosaic, in the South than in Nebraska. It has been noticeable, however, in many of the yield tests that there is a considerable variation in the amount of mosaic present in different strains of potatoes giving about the same yields and *vice versa*. An example of this is shown by Edgerton and Tiebout (1921, p. 11). Their data show that Lots Nos. 2 and 3 have practically the same yield, but differ in the amount of mosaic by about 30 per cent. Again, Lot No. 10 outyields Lot No. 5 by about 55 bushels, altho the amount of mosaic is the same in both cases. This can be accounted for by the possibility that different types of mosaic were present, together with the fact that different types of mosaic affect the yield rate differently. Very little evidence has been published on this point, and more information is needed to determine the tolerance of different types of these diseases to be allowed in our seed potatoes for different localities.

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Regarding the control of these diseases, a great number of factors must be taken into consideration, but do not properly belong in this paper, except for certain phases of the problem in relation to environment. The general methods of control usually advised have comprised roguing, selection of healthy hills, seed plats, and isolation. Schultz and Folsom (1921, p. 75) have noted a regional variation in the amount and spread of mosaic in experimental fields, apparently due to the effect of climate on the amount of aphid infestation. Quanjer (1921, p. 143) found a difference in the spread of leaf roll and related diseases when parts of split tubers were planted in different localities. He found more green flies present in localities where the disease spread the most, but apparently does not think this is the sole explanation. Murphy (1921) has also noted regional differences in the spread of mosaic.

Thus the effect of environment is of considerable importance in determining the degree of isolation necessary in seed plats. The amount of infestation is important as regards the time of roguing or of hill selection. The direct effect of masking on the ability to distinguish and remove diseased plants is obvious.

Another factor in relation to control is the possible transmission of the disease from native plants, and this again will vary in different localities.

This short review of the literature must lead one to the conclusion that environment exerts a marked influence upon the symptoms, the spread, and the effect on yield of these diseases. The exact conditions causing the masking of symptoms and the degree of masking, still remain to be demonstrated for the various types of mosaic in different varieties, and practically no information is given regarding the effect of such factors on the spindle-tuber disease. Until the effect of these external factors on the appearance, spread and yield is determined for the different varieties and for the different diseases, it is manifestly impossible to come to a clear understanding of these diseases in the various potato growing sections and to combat them intelligently. The problem still remains in many ways purely a local one.

Conditions in Nebraska and other dry land sections of the West are markedly different from those prevailing in the East, where most of the experimental work in the United States on these diseases has been performed. It has long been evident that experimental results from eastern states cannot be applied, *in toto*, to the potato sections of the West. Conditions of temperature, moisture, sunlight, aphid infestations (usually very scarce),

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and possible native hosts other than the potato are very different from those occurring in the East. The varieties being grown are not those upon which most of the reported experiments have been conducted. The appearance of these diseases and even the severity of the different types in their effect on yield are very diverse. Increases in mosaic in the absence of great numbers of aphids are common. The necessity for further work on this problem in various parts of the country, but particularly in the West, even at the risk of considerable duplication, cannot be too greatly emphasized.

EXPERIMENTAL DATA

GREENHOUSE EXPERIMENTS

EFFECT OF TEMPERATURE ON THE SYMPTOMS DECEMBER 22, 1922, TO APRIL 16, 1923

The following experiment was planned to determine the effect of temperature on the symptoms of certain degeneration diseases in the Bliss Triumph variety.

Source of Seed.—The seed used in this and the following experiments, except where otherwise noted, was obtained from Dr. Donald Folsom, Maine Agricultural Experiment Station, August 20, 1922, and was designated by him as follows: mild mosaic, medium plus mosaic, spindle-tuber, spindle-tuber+mild mosaic, and curly dwarf (spindle-tuber+leaf rolling mosaic).

In a recent publication, Schultz and Folsom (1923) state that their former designation of medium plus mosaic is in part a combination of rugose mosaic with spindle-tuber. The material sent to the author undoubtedly shows both mosaic and spindle-tuber characteristics on the vine and spindle-tuber symptoms on the tubers, but has not appeared as serious as the spindle-tuber+mild mosaic.

Methods.—One tuber from each of these 5 lots of seed was cut into 4 equal sized pieces and used for planting at 4 different temperatures. Thus all 4 plants listed in Table 1 under each disease were from the same mother tuber.

The plants were grown in 10,000 gms. of soil in galvanized iron containers in which the soil moisture was kept approximately constant by methods previously described by the author, Goss (1923). The soil was held at 22 per cent moisture (dry weight), this being equal to the soil moisture equivalent.[1] Immediately after planting, the containers were placed at the de-

[1]The author is indebted to Mr. J. C. Russel of the Agronomy Department, Nebraska College of Agriculture, for the determination of soil moisture equivalents.

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sired temperature. The temperatures used were 15°, 20°, 25°, and 30° C. These temperatures were held constant for both air and soil in temperature cases described by Peltier (1923). On February 9, when the plants were half grown, they were transferred to different temperatures, the plants at 15° and 20° being removed to a greenhouse held at approximately 25°. The plants at 25° and 30° were transferred to temperature cases held at 15°.

The light conditions were approximately the same in all cases. The sunlight during the experiment was very weak, and as a result the plants were considerably etiolated.

Observations were made every week during the experiment, and after the temperatures were changed, observations were made separately on the old and new foliage. Healthy tubers were grown in each set as controls, and in every instance remained healthy except for chlorosis and leaf dropping at the high temperatures, so that these symptoms were not recorded for the mosaic plants. The extent of dwarfing was determined by comparing the infected plants with the controls in the same sets.

Results.—A summary of the symptoms appearing on the individual plants is given in Table 1. The results show a rather uniform and marked gradation in the absence or in the severity of the symptoms of the various plants growing at different temperatures. More symptoms were present and they were all more distinct at 15° than at 20° C. At 25° the mild mosaic plant appeared healthy while at 30° many of the symptoms on all plants were absent. When plants growing at 15° were transferred to 25°, the symptoms usually persisted in a milder form on the old leaves, while in most instances the new leaves appeared healthy. The symptoms persisted longer on these plants than on the plants transferred from 20° to 25°. The reverse was true on plants grown at 25° and 30° and transferred to 15°. Here the old leaves sometimes developed symptoms under the more favorable temperature conditions while in most instances the new leaves showed very distinct symptoms. These were never as distinct on the plants previously grown at 30° as on those grown at 25°, and in most instances they were not as distinct even on the new leaves at 15° as they were on plants started at 15°. Evidently the high temperatures not only masked the symptoms, but inhibited the development of the symptoms when the plants were changed to a lower temperature.

Contrary to expectations, under the conditions of this experiment, mottling of the leaf was the most persistent symptom present; this was possibly favored by the weak sunlight conditions.

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TABLE 1.—*Effect of temperature upon the symptoms of certain degeneration diseases appearing on the foliage developed during the period of growth, (I) before and (II) after the change of temperature*[1]

Planted December 22—Temperature changed February 9, plants dug April 16

Plant No.	Period of growth	Temp. °C.	Foliage formed before or after temperature change	Symptoms						Miscellaneous notes
				Dwarfing	Mottling	Wrinkling	Rugosity	Ruffling	Curling	
MILD MOSAIC										
1	I	15	Before		±	—	±	±	±	
	II	25	Before		—	0	—	—	—	
			After		0	0	0	0	0	
2	I	20	Before		±			±		
	II	25	Before		—			—		
			After		0			0		
3	I	25	Before		0	0	0	0	0	
	II	15	Before		—	0	0	0	0	
			After		±	—	±	±	±	
4	I	30	Before		0	0	0	0	0	
	II	15	Before		0	0	0	0	0	
			After		—	—	—	—	—	
MEDIUM + MOSAIC										
1	I	15	Before		+	+	+	+	+	Tubers S. T.−
	II	25	Before		±	—	±	±	—	
			After		—	0	0	0	0	
2	I	20	Before		±	±	±	±		Tubers S. T.−
	II	25	Before		—	0	—	—		
			After		—	0	0	0		
3	I	25	Before		—		0	0	0	Tubers S. T. +
	II	15	Before		±		0	0	0	
			After		+		+	+	+	
4	I	30	Before		—			—		Tubers S. T.−
	II	15	Before		—			—		
			After		—			—		

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TABLE 1.—CONCLUDED.—*Effect of temperature upon the symptoms of certain degeneration diseases appearing on the foliage developed during the period of growth, (I) before and (II) after the change of temperature*[1]

Planted December 22—Temperature changed February 9, plants dug April 16

Plant No.	Period of growth	Temp. °C.	Foliage formed before or after temperature change	Symptoms: Dwarfing	Mottling	Wrinkling	Rugosity	Ruffling	Curling	Miscellaneous notes
SPINDLE-TUBER + MILD MOSAIC										
1	I	15	Before	±	+	±	+	+	+	Uprightness
	II	25	Before	±	±	—	±	±	±	Tubers S. T. +
			After	±	—	0	0	—	0	
2	I	20	Before	±	+			+		Uprightness
	II	25	Before	±	—			—		Brittleness
			After	±	0			0		Tubers S. T. ±
3	I	25	Before	±	—		0	—	0	Uprightness
	II	15	Before	±	—		0	—	0	Brittleness
			After	±	+		±	+	±	Tubers S. T. +
4	I	30	Before	—	—			--		
	II	15	Before	—	—			—		Tubers S. T. +
			After	—	—			-		
CURLY DWARF										
1	I	15	Before	+	+	+	+	+	+	Slight rolling
	II	25	Before	+	+	±	+	+	+	Uprightness
			After	+	±	0	+	+	+	Brittleness
2	I	20	Before	+	±	±	—	—	±	Uprightness
	II	25	Before	+	±	—	—	—	±	Tubers S. T. +
			After	+	—	0	—	—	—	
3	I	25	Before	+	—	0	0	0	0	Slight rolling
	II	15	Before	+	+	—	±	±	+	Uprightness
			After	+	+	—	+	+	+	Tubers S. T. ±
4	I	30	Before	+	0		0	0	0	Slight rolling
	II	15	Before	+	±		0	±	0	Uprightness
			After	+	±		±	±	±	Tubers S. T. ±

[1]The symbols designate the severity of the symptoms, i. e., + = very distinct, ± = moderately distinct, — = slight, 0 = absent.

The absence of any symbol indicates that the symptom did not appear at any time during the experiment.

[2]The abbreviation S. T. under miscellaneous refers to the spindle-tuber symptoms on the new tubers.

Wrinkling was probably the least permanent symptom. When

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The symptoms of spindle-tuber were apparently less influenced by temperature than those of mosaic. The erectness, spindleness, and slight dwarfing of the vine along with the ruffling of the leaves and the tuber symptoms, remained fairly constant at all temperatures.

The results presented here show that a temperature somewhere between 20° and 25° is the critical point in determining the presence or absence of mosaic symptoms. As the temperature is increased the symptoms tend to disappear, while the reverse is true of lower temperatures. The data presented here agree in general with those of Johnson (1922).

One important fact that will be noted later in connection with field observations was the apparent greater severity of mild mosaic under certain conditions, for example at 15°, than a more severe type, such as medium plus mosaic or curly dwarf, growing under a different set of conditions, for example at 30° C.

It must be remembered that in this experiment only one environmental factor was varied and that variation in other factors would probably cause a change in the apparent temperature effect on symptoms.

It is true that the seed used in this experiment may have been infected with other diseases the previous year, as they had been grown in the field subject to infection. However, this experiment was not conducted in any attempt to prove or disprove the previous diagnosis of the disease and the fact that the plants of each disease type at each temperature were grown from the same tuber eliminated to a great extent all factors other than the one under consideration, *i. e.*, temperature.

It is evident from this one experiment, and from other tests made showing the same results, that the symptoms of these diseases may vary so greatly under different conditions that it would be an impossible task to attempt to classify such diseases in commercial fields. While it may be held that this experiment was conducted under different conditions from those occurring in the field, it will be shown later that such results can be obtained under field conditions.

EFFECT OF SUNLIGHT ON THE SYMPTOMS
FEBR. 19, 1923, TO MAY 25, 1923

Using mild mosaic, medium plus mosaic, and curly dwarf seed tubers from the same source as in the previous experiment, a preliminary test was made of the effect of shading on mosaic symptoms. Tubers from these 3 lots were halved and one-half grown in direct sunlight while the other half was grown under

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2 thicknesses of cheesecloth. Healthy tubers were planted and grown under the same conditions. The air temperature was kept at approximately 18° C. and the soil was kept at a rather high soil moisture content.

The mottling of the foliage was in every instance more distinct under shade than in the sunlight altho it was present on all plants. Rolling, streaking, and burning were present on the medium plus mosaic and curly dwarf plants in the sunlight and absent under shade. The streaking occurred only on the stems and petioles. Wrinkling, ruffling, rugosity, brittleness and curling varied considerably during the experiment both in sunlight and shade and no clear cut difference was noted under the 2 conditions. Rolling, uprightness, rigidity, streaking, and dwarfing were present in medium plus mosaic and curly dwarf plants and absent in mild mosaic plants. In all instances the symptoms were more severe in curly dwarf plants.

While the number of plants was small, a clear cut difference was present in regard to mottling and rolling.

More extensive and carefully controlled experiments may show differences in the appearance of other symptoms not evident in this preliminary test.

There was a distinct difference in what might be termed the severity of the disease, with the 3 types used under both conditions.

FIELD EXPERIMENTS

In 1923 experiments were conducted in an effort to determine the effect of environmental conditions on the symptoms of these diseases in the field.

Methods.—Experimental plots were located in various sections of western Nebraska. The potatoes were grown under different conditions and with different dates of planting as follows:

Plot A—Planted May 15—Scotts Bluff Substation, Mitchell, Nebraska.

Plot B—Planted May 15—Scotts Bluff Substation, Mitchell, Nebraska, irrigated.

Plot C—Planted June 1—Scotts Bluff Substation, Mitchell, Nebraska, irrigated.

Plot D—Planted June 1—August Gadeken's farm, Bushnell, Nebraska.

Plot E—Planted May 10—Muldoon farm, Dawes table, Chadron, Nebraska.

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Plot F—Planted June 1—Muldoon farm, Dawes table, Chadron, Nebraska.

Plot G—Planted June 20— Muldoon farm, Dawes table, Chadron, Nebraska.

In each of these plots potatoes were planted from the same source and with the same diseases as those listed on page 10. The seed used was cut into pieces averaging about 30 gms. in weight. When possible, the different pieces from the same tuber were planted in different plots in sequence. In other cases,

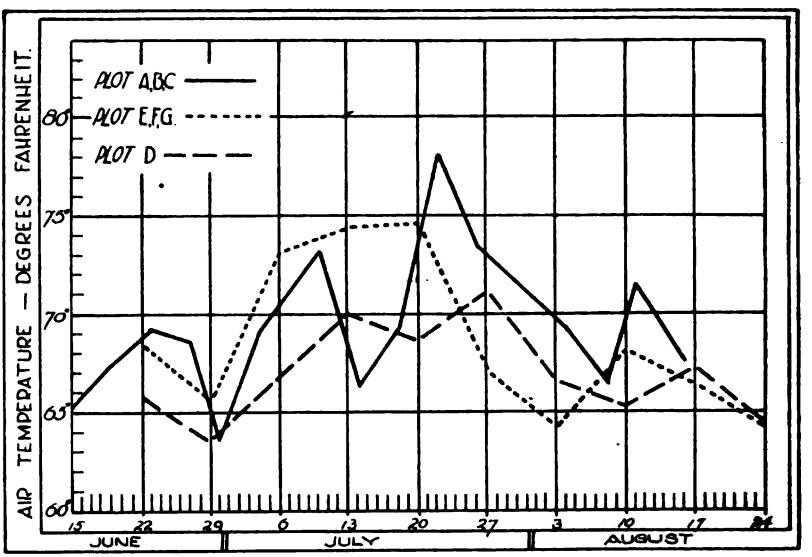

FIG. 1.—Graph showing air temperatures for all 1923 Experimental Plots.
Plots E, F, G, and D represented by mean weekly temperatures.
Plots A. B. and C represented by the mean temperatures for the periods between the mosiac readings as listed in Tables 2-7.
All mean temperatures obtained from 2-hour readings, i.e., 12 readings every 24 hours instead of using maximum and minimum temperatures.

tubers from the same hill were used similarly. Air temperature records were kept at each plot (figure 1) and soil moistures were also determined weekly in the plots located at Mitchell. Rainfall and sunshine records were obtained from the U. S. Weather Bureau records made at the Substation. In Plots A and B, notes were taken on the date of emergence, and the mosaic readings were made at least once a week until the middle of August, partly by the author and partly by Mr. William Morrow, Field Assistant. In the other plots, readings were

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made 3 times during the season by the author. At digging time, all hills were dug, weighed and graded separately.

Results.—No attempt will be made here to take up the records of the symptoms occurring on the individual plants of each plot, but some specific examples of the effect of external conditions on the appearance of the symptoms will be shown. In general it can be said that the differences in symptoms between the different plots were no greater than the differences observed during the season in any one plot. As an example,

TABLE 2.—*Symptoms appearing on mild mosaic plants. Plot A (8 plants)*[1]

Date	Dwarfing	Chlorosis	Mottling	Wrinkling	Ruffling	Rugosity	Curling	Rolling	Uprightness	Rigidity	Brittleness	Spotting	Streaking	Burning	Leaf dropping
June 15			2		1	1									
June 19			1	1		1									
June 23				1		1		1							
June 27				1											
June 30									1	1	1				
July 4															
July 10															
July 14			3	2	1	2	2								
July 18				1		1									
July 22				1	2	1									
July 26			3	1	2	2	1	1							
Aug. 4			5	3	3	3	1	2							
Aug. 8			4	2	2	2	1	2							
Aug. 11			4	2	2	3	1	3							
Aug. 16			1	3	2	3	2	2							

[1]The symbols used in Tables 2—5, 7 and 8 refer to the degree of severity of each symptom as represented by figures 1 to 5, the extremes being: 1—"very slight" and 5—"very severe." These were the average symptoms on all plants. Usually the symptoms were identical or nearly so in all plants of each disease. The omission of any symbol indicates that the symptom did not appear.

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the changes will be shown in detail only for Plot A. In examining the following tables, it is well to keep in mind the temperature curves shown in figure 1.

The most marked differences occurred, as in the greenhouse experiment, with the mild mosaic plants. It will be seen from Table 2 that the symptoms during the early season were not very reliable, but as the season progressed they became more fixed. Comparing Table 2 with the temperature curve shown in figure 1 for Plot A, it will be seen that from June 30 to July 10 the temperature rose rapidly, and this corresponds with the disappearance of the few symptoms previously present. A sharp drop in temperature after the 10th accompanied by 0.8 inch of rain and a decrease in sunshine resulted in the reappearance of the symptoms in a more serious form. This was followed by another sharp rise in temperature resulting in the disappearance of mottling and a smoothing out of the previously wrinkled leaves. It is evident that with the increased age of the plant the effect of temperature on such symptoms as wrinkling and rugosity is not as marked as on the younger plant. Another drop in temperature accompanied by rainfall resulted in the second reappearance of mottling as well as other leaf symptoms, which continued to be very evident thruout the remainder of the season during which records were obtainable. While the mottling showed greater changes than appeared in the greenhouse experiment, the author believes this to have been due to the fact that the intense sunlight occurring during these periods of high temperature was great enough to cause these changes, while in the greenhouse, as already noted, the sunlight was weak. At the altitude of this experiment, about 4,000 ft. as in many other regions of the West, the sunlight is intense enough during the middle of the day to cause the leaves to droop and become flaccid.

In Table 3 are shown the symptoms for the plants listed as "medium plus mosaic", also in Plot A. We find the same general changes as shown in Table 2. The mottling was not as evident on these plants as on those listed as mild mosaic. However, this mottling and also curling showed the greatest effects of temperature changes, altho the severity of all other leaf symptoms was also decreased during the same periods. The addition of uprightness and rigidity to the list of symptoms as well as the increase in ruffling was probably due to the spindle-tuber apparently present in this combination called medium plus mosaic. Other symptoms, as rugosity and curling, were greater than in mild mosaic. The same general relation to the effect of temperature is evident.

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TABLE 3.—*Symptoms appearing on medium plus mosaic plants. Plot A (5 plants)*[1]

Date	Dwarfing	Chlorosis	Mottling	Wrinkling	Ruffling	Rugosity	Curling	Rolling	Uprightness	Rigidity	Brittleness	Spotting	Streaking	Burning	Leaf dropping
June 15	...	...	...	1	1	1	...	...	...	...	...	...	...	...	...
June 19	...	...	...	1	1	2	1	...	...	...	...	...	...	...	...
June 23	...	...	...	1	1	1	...	...	...	...	...	...	...	...	...
June 27	...	...	...	1	1	1	...	...	...	...	...	...	...	...	...
June 30	...	...	1	1	1	1	...	2	1	1	...	...	...	...	...
July 4	...	...	...	1	1	1	2	2	1	...	...	...	...	...	...
July 10	...	...	...	1	1	2	...	3	1	1	...	...	...	...	...
July 14	...	...	2	2	2	4	2	5	...	...	...	...	...	...	...
July 18	...	...	...	1	2	2	...	1	1	...	...	...	...	...	...
July 22	...	...	...	1	2	2	2	2	1	...	...	...	...	...	...
July 26	...	...	1	2	3	3	3	2	1	...	...	...	...	...	...
Aug. 4	...	...	2	3	3	3	3	4	1	...	...	...	...	...	...
Aug. 8	...	...	1	3	3	4	2	3	...	...	...	...	...	...	...
Aug. 11	...	...	1	3	3	4	2	3	...	...	...	...	...	...	...
Aug. 16	...	...	1	4	3	4	2	3	...	...	...	...	...	...	...

[1]For explanation of symbols see Table 2.

In Table 4 are listed the symptoms of plants affected with spindle-tuber+mild mosaic. These plants appeared more seriously diseased than the medium plus mosaic plants. The uprightness and rigidity of the plants were more marked, and dwarfing occurred that was not evident in the other plants listed in Tables 2 and 3. A decrease in the germinating power of such seed was also evident.

Here again the same general effect of temperature on the symptoms was noticeable. Mottling was the least permanent symptom. The other leaf characters showed very slight changes

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TABLE 4.—*Symptoms appearing on spindle-tuber+mild mosaic plants. Plot A (4 plants)*[1] [2]

Date	Dwarfing	Chlorosis	Mottling	Wrinkling	Ruffling	Rugosity	Curling	Rolling	Uprightness	Rigidity	Brittleness	Spotting	Streaking	Burning	Leaf dropping
June 15	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...
June 19	...	...	...	1	...	...	...	...	...	1	...	...	...	...	...
June 23	...	...	...	1	...	...	...	...	...	2	...	...	...	...	...
June 27	...	...	1	1	...	...	...	...	...	2	...	...	...	...	...
June 30	...	...	...	2	...	...	...	...	1	2	...	...	...	...	...
July 4	1	...	...	2	2	2	...	2	1	1	...	...	...	...	...
July 10	2	...	...	...	3	2	1	4	2	...	...	...	...	...	...
July 14	1	...	1	2	4	3	3	2	2	...	...	...	...	...	...
July 18	1	...	...	2	3	3	2	3	3	...	...	...	..	...	...
July 22	1	...	1	2	3	2	3	3	1	...	...	...	...	...	...
July 26	...	...	5	4	2	4	5	3	4	...	...	...	...	...	...
Aug. 4	...	...	5	3	2	3	3	3	5	...	...	...	...	...	...
Aug. 8	...	1	5	2	1	2	3	2	2	...	...	...	...	...	...
Aug. 11	...	1	5	2	2	2	2	2	2	...	...	...	...	...	...
Aug. 16	...	1	4	2	2	2	2	3	2	...	...	...	...	...	...

[1] For explanation of symbols see Table 2.
[2] Three seed pieces failed to germinate. Average germination 8 days later than mild mosaic plants.

that could be correlated with temperature, indicating that the more serious the manifestation of disease, the less will be the effect of external factors.

Table 5 shows the symptoms of curly dwarf plants listed in the same manner. The effects of changes in temperature as noted for the other disease types were here hardly discernible. The greatest change noticeable in the field was in regard to rigidity and brittleness which decreased during the hot, dry periods. It is true, however, that if the numerical symbols representing the severity of the symptoms be added for the

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TABLE 5.—*Symptoms appearing on curly dwarf plants. Plot A (4 plants)*[1]

Date	Dwarfing	Chlorosis	Mottling	Wrinkling	Ruffling	Rugosity	Curling	Rolling	Uprightness	Rigidity	Brittleness	Spotting	Streaking	Burning	Leaf dropping
June 15	1	...	...	...	...	...	...	...	...	...	...	...	...	...	....
June 19	1	...	...	2	...	...	...	...	...	...	...	...	...	...	....
June 23	2	...	1	2	1	2	1	1	...	1	...	...	...	...	....
June 27	3	...	1	1	1	1	...	...	...	2	...	...	...	...	....
June 30	3	...	...	1	...	...	...	...	2	...	...	...	...	...	....
July 4	5	...	...	4	5	4	4	2	4	4	...	...	...	...	....
July 10	5	...	...	3	4	5	2	3	3	1	...	...	...	1	1
July 14	5	...	...	3	5	5	4	4	2	1	1	...	...	...	....
July 18	5	...	...	3	5	5	3	5	2	...	...	...	...	...	....
July 22	5	...	...	4	3	4	4	3	4	...	...	...	...	...	....
July 26	5	...	...	5	4	5	5	5	5	...	3	...	...	...	....
Aug. 4	5	...	...	5	3	5	5	4	5	1	2	...	...	...	....
Aug. 8	5	1	...	3	3	4	5	4	3	2	...	...	1	2	1
Aug. 11	5	2	...	5	3	5	5	4	4	2	...	...	1	5	....
Aug. 16	Practically defoliated with early blight														

[1]For explanation of symbols see Table 2.

various dates it will be found that there was again a slight de-

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It is evident from this experiment that the differences observed on these plants during the season were so great that a reading for mosaic percentages or for disease types made during certain parts of the season would be subject to great error.

TABLE 6.—*Soil moisture expressed as per cent of moisture equivalent. Plots A, B, and C, 1923*

	June			July				August				September	
	10	19	26	3	10	18	25	2	9	18	25	5	8
Plot A....	112	88	84	67	89	81	76	63	84	94	69	54	.....
Plot B....	96	71	57	52	48	52	65	66	66	87	74	34	86
Plot C....	105	77	84	84	80	70	74	59	70	100[1]	73	40	102[1]

[1]Irrigated.

TABLE 7.—*Symptoms on mild mosaic plants. Plot B (8 plants)*[1]

Date	Dwarfing	Chlorosis	Mottling	Wrinkling	Ruffling	Rugosity	Curling	Rolling	Uprightness	Rigidity	Brittleness	Spotting	Streaking	Burning	Leaf dropping
June 15	...	...	...	2	...	...	...	...	...	...	...	...	...	...	...
June 19	...	...	...	1	...	1	1	...	...	...	...	...	...	...	...
June 23	...	...	1	1	...	1	...	...	...	...	...	...	...	...	...
June 28	...	...	...	1	...	1	...	...	...	...	...	...	...	...	...
July 4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
July 10	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
July 14	...	...	1	1	...	1	...	...	...	...	...	...	...	...	...
July 18	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...
July 22	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Aug. 4	...	...	2	2	1	2	...	...	...	...	...	...	...	...	...
Aug. 8	...	...	4	2	1	2	1	1	...	...	...	...	...	...	...
Aug. 11	...	...	5	2	2	3	1	2	...	...	...	...	...	...	...
Aug. 15	...	...	5	3	2	4	1	2	...	...	...	...	...	...	...

[1]For explanation of symbols see Table 2.

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It is also seen that readings on these diseases taken under diverse conditions and at different stages of growth would be subject to considerable error. For example, the medium plus mosaic plants on July 18 and 22 did not show as serious symptoms as the mild mosaic plants on July 26 and August 4.

In comparing these symptoms with those of the corresponding plants in Plot B, it was found that the symptoms thruout the season were not as serious as in Plot A. The mild mosaic plants of Plot B are described in Table 7 as an example of the differences occurring. If this table be compared with the corresponding Table 2 for Plot A, it will be seen that the same differences in regard to temperature effects were present, but that all symptoms were less severe than in Plot A. One of the differences in the external factors between these plots is shown in Table 6, representing the soil moisture as per cent of the soil moisture equivalent. It is evident that the plants in Plot B were grown under drier conditions, and this may have had some effect on the symptoms. While this was an irrigated plot, no irrigation was made until after August 15, *i. e.*, after the last mosaic readings, because of the abnormally wet weather. There were, however, other differences in the soil of these plots that may have contributed to the effect. Plot B was a medium silt loam, while Plot A was a light sandy loam. The temperatures were about the same, that is, the plots were located on the same farm. Whether or not the soil moisture was chiefly responsible for the differences in symptoms is not entirely clear. Soil moisture experiments are being conducted in the greenhouse under control conditions to obtain more information on this point.

Effect of Date of Planting on the Symptoms.—This test was made to determine the influence of the age of the plants on their reaction to environment, as shown by changes in the symptoms.

The 3 plots designated as E, F, and G were planted at 20-day intervals as follows: Plot E on May 10, F on June 1, and G on June 20. All plots were in the same field.

As in previous experiments, the mild mosaic units were more influenced by environmental conditions than were the other units and will be used for an example.

Three readings were made, on July 6, July 18, and August 20. The temperature record of these plots is shown in figure 1. The mild mosaic readings are listed in Table 8. In this table the readings for the mild mosaic plants in Plot D are also listed.

Reference to the temperature record for these plots in figure 1 will show a distinct correlation between the rise in temperature and the disappearance of the symptoms. The mean weekly

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TABLE 8.—*Symptoms on mild mosaic plants, as related to date of planting*[1]

Date	Days after planting	Dwarfing	Chlorosis	Mottling	Wrinkling	Ruffling	Rugosity	Curling	Rolling	Uprightness	Rigidity	Brittleness	Spotting	Streaking	Burning	Leaf dropping
PLOT E PLANTED MAY 10																
July 6	57	...	...	2	1	2	2	3	2	...	...	...	...	...	...	...
July 18	69	...	...	1	1	1	...	1	...	...	...	...	...	...	...	...
PLOT F PLANTED JUNE 1																
July 6	36	...	...	1	1	1	1	1	...	...	...	...	...	...	...	...
July 18	48	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Aug. 20	81	...	...	2	3	3	5	...	5	...	...	...	...	...	...	...
PLOT G PLANTED JUNE 20																
July 18	28	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Aug. 20	61	...	...	1	1	3	3	1	1	...	...	...	...	...	...	...
PLOT D PLANTED JUNE 1																
July 3	33	...	...	1	2	...	2	1	...	...	...	...	...	...	...	...
July 26	56	...	...	2	3	1	3	...	3	...	...	...	...	...	...	...
Aug. 24	85	...	...	2	3	2	2	2	5	...	...	...	...	...	...	...

[1]For explanation of symbols see Table 2.

temperatures had been low during the early growth of the plants in Plot E and even tho the mean temperature rose to 73° F.

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on the plants in Plot F. The older plants in Plot E showed symptoms that were slighter, but that still were as evident as those in Plot F at the previous reading. No symptoms were present on the young plants in Plot G.

The period from the second to the third readings, July 18 to August 20, showed a marked decrease in temperature, and its effect was made evident by the reappearance of the symptoms in Plot F in a severe form, and by the first appearance of symptoms of the disease in Plot G. The plants in Plot E were mature at this time.

It is again evident that the older the plant is the slighter will be the effect of weather conditions that are unfavorable for the appearance of disease symptoms, while in a young plant the symptoms either will fail to appear or may disappear during hot weather only to appear later during a period of lower temperature. It may also be noted that the late planting in Plot G did not show symptoms until very late in the season, so that diseased hills in commercial fields planted late and growing under such weather conditions as were present here, might easily be missed if inspections were made early in the season. In the same way, if inspections were made during periods of hot weather, the disease in young plants such as those in Plot F would not be detected.

The other mosaic units showed somewhat similar reactions, but some symptoms were present at all readings. Apparently the more severe diseases or combinations of diseases were less influenced by the environment, as was found in Plot A.

Considering all the units in general in Plots E, F, and G, it may be said that the mosaic symptoms were more severe in the earlier plantings while the reverse was true of the spindle-tuber symptoms.

The plants listed in Plot D, grown from the same units as those in the other plots, showed more distinct symptoms on the mild mosaic units thruout the season. A glance at the temperature record in figure 1 will show that the temperatures were always lower than at the other plots listed. The seed was planted at about the same time as in Plot F, and the readings

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TABLE 9.—*Average yields in grams per plant from diseased types from all plots. 1923 experiments*

	Number of plants	Total weight	Marketable
		Grams	*Grams*
Mild mosaic	47	435	336
Medium plus mosaic	24	264	197
Mild mosaic + spindle-tuber	39	189	112
Spindle-tuber	25	173	63
Curly dwarf	25	86	20

so evident that the data were collected. In Table 9 are shown the average yields per plant. This is made up from all of the 6 plots previously listed. The number of plants was so small and the experimental error would be so great that no attempt was made to compare yields of the various plots. The averages here presented are fairly representative. The mild mosaic units in every case gave the greatest yield. The medium plus mosaic and the mild mosaic+spindle-tuber units varied in the different plots and gave about the same yield, being considerably less than the mild mosaic. Spindle-tuber alone reduced the yields in every plot to a point approaching that of curly dwarf. Practically 100 per cent of the tubers produced by the mild mosaic+spindle-tuber plants and by spindle-tuber alone were of the very severe elongated type with numerous shallow eyes characteristic of tubers affected with spindle-tuber, while curly dwarf plants produced 40 per cent of this type of tubers, indicating the presence of spindle-tuber in this symptom complex. Medium plus mosaic evidently has its spindle-tuber characteristics masked to

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FIELD EXPERIMENTS WITH MISCELLANEOUS MOSAIC

In 1921 a few preliminary experiments were started to study the effect of environment on the symptoms and yields of mosaic seed.

Methods.—A number of tuber units of Bliss Triumph mosaic seed and also a number of units of rogued Bliss Triumph were obtained from Maine.[1] Another lot of seed containing a high percentage of mosaic was obtained from Minnesota. Control rows were planted with certified Bliss Triumphs from Nebraska.

The seed was divided by cutting the potatoes in 3 pieces and planting at 3 different locations, as follows:

Plot 1—Planted April 20 at Lincoln, Nebraska.

Plot 2—Planted May 20 at the Substation at Mitchell, Nebraska, dry land culture.

Plot 3—Planted May 20 at the Substation at Mitchell, Nebraska, irrigated.

TABLE 10.—*Mean weekly air temperature for comparative weeks for plots 1, 2, and 3, 1921*

	Comparative weeks[1]									
	1	2	3	4	5	6	7	8	9	10
Plot 1.....	57	57	81	76	69	79	79	78	80	79
Plots 2 and 3..	73	69	79	69	78	79	76	71	73	73

[1]Plot 1—Temperatures for May 4 to July 13 inclusive.
Plots 2 and 3—Temperatures for June 10 to August 19 inclusive.

Table 10 shows the mean weekly air temperature at the 3 plots during the experiment. Further details regarding these plots have been previously described. Goss (1923). No aphids were observed in any of these plots during the season.

Results.—Table 11 gives the data on the percentage of disease present and on the yields resulting from these tests. The mosaic readings were based chiefly on the leaf symptoms. The mosaic plants in all plots showed a slight dwarfing so that the rows were distinguishable. No attempt was made to examine each individual plant any more closely than would be done in certification work. In general, the Maine mosaic seed showed the greatest amount of disease and produced the lowest yield in all plots. The Maine

[1]Seed obtained from Dr. E. S. Schultz, U. S. Dept. of Agriculture.

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TABLE 11.—*Disease percentages and yields for 1921 experiments*

	Number of seed	Per cent germination	Per cent of disease			Total yield in grams per plant	Total yield per plant based on checks as 100 per cent
			Distinct mosaic	Mild mosaic	No symptoms		
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Grams*	*Per cent*
PLOT 1							
Checks	217	97.6	7.0	9.4	83.4	187	100
Maine rogued	61	98.3	20.4	50.0	29.5	170	90
Maine mosaic	46	95.6	40.0	48.3	11.6	77	41
Minnesota mosaic	235	96.1	28.7	35.3	35.8	143	76
PLOT 2							
Checks	220	61.8	.....	.....	.....	374	100
Maine rogued	94	42.5	25.0	27.5	47.5	336	89
Maine mosaic	48	50.0	8.3	62.5	29.1	189	50
Minnesota mosaic	205	73.1	16.0	26.0	58.0	247	66
PLOT 3							
Checks	219	65.7	.....	.....	.....	973	100
Maine rogued	94	73.4	5.7	5.7	88.4	669	68
Maine mosaic	48	81.2	5.1	15.3	79.4	562	57
Minnesota mosaic	211	83.8	4.5	8.4	87.0	818	84

rogued seed ran about the same as the Minnesota mosaic seed, while the controls showed the lowest amount of disease and the highest yields.

When comparing the different plots it is evident that the greatest amount of disease appeared in Plot 1, with Plots 2 and

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ture averaged above 70° F. at this time and during the preceding weeks. The difference in the amount of disease between Plots 2 and 3 is not so easily explained because the temperatures were practically the same. Plot 3 was irrigated and the soil moisture during most of the experiment was higher than in Plot 2, but nevertheless the amount of mosaic symptoms appearing during the experiment was very small. The soil in Plot 3 was more fertile and the plants made a much more rapid and vigorous growth, as evidenced by the yields.

It might be noted here that the conditions in Plot 1, where the greatest amount of disease was observable and where the lowest yields were obtained, were very similar to conditions prevailing in the southern potato states as will be pointed out later. A very low mean temperature and high soil moisture during the early growth of the plant favored the development of mosaic symptoms, and a very high temperature during the later part of the season was unfavorable for normal tuber development.

It is clearly evident from these results that the time of making an examination in the field and the conditions under which the plants are growing must be considered if accurate percentage readings of mosaic are to be made.

In 1922 a composite sample of the Maine mosaic seed from all three 1921 plots, comprising 330 plants, was planted at Lincoln on May 5. It might be expected that a considerable increase in the amount of mosaic would occur. Nevertheless several readings made during June and July showed only 5.6 per cent of distinct mosaic. There was some dwarfing and curling of leaves of all plants, but this was also present on the plants in the control rows planted with certified seed. The healthy rows could not be distinguished from the mosaic. The abnormal appearance of the leaves as well as the low percentage of mosaic can probably be explained by an examination of the temperature records for this year. The mean temperature during June and July when the mosaic readings were made was 75° F. for each month, and the soil moisture was considerably lower than in 1921. The germination and yield both total and marketable were as high for the mosaic rows as for the checks.

In 1923, seed from the 1922 plot was divided by cutting tubers into a number of pieces and by dividing the tubers from the same hills so that corresponding seed pieces from the same hill were obtained. These were planted in the 7 different plots described on page 15. Mosaic readings were made at least 3 times during the season. The results tabulated in Table 12 are made up from the total symptoms, that is, if a plant showed distinct mosaic at any time during the season, it was listed

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TABLE 12.—*Disease percentages from miscellaneous mosaic experiments, 1923*

	Number of seed	Per cent germination	Per cent of disease		
			Distinct mosaic	Mild mosaic	No symptoms
		Per cent	*Per cent*	*Per cent*	*Per cent*
Plot A	112	93	26.6	49.5	17.1
Plot B	131	96	8.6	41.7	49.6
Plot C	131	99	6.9	53.8	39.2
Plot D	162	81	25.7	46.9	27.2
Plot E	52	100	17.2	53.8	28.8
Plot F	157	92	11.6	46.5	39.7
Plot G	147	93	7.9	11.5	80.4

under that heading. The increase in the amount of distinct mosaic in Plot A over Plots B and C was again evident. The conditions influencing this have already been discussed on page 23. Plot D as in the previous experiment showed a large amount of mosaic. The most noticeable difference, however, occurred in Plots E, F, and G. These, as already noted, were planted in the same field at intervals of 20 days. It was noticeable that the first planting in Plot E showed by far the greatest amount of mosaic, and that there was a considerable decrease in the next planting, Plot F, while in the last planting, in Plot G. 80 per cent of the vines appeared healthy.

It must be remembered that these different percentages of mosaic were found on plants obtained from the same seed and that this seed was from the 1922 experiments grown in turn from the plants listed in Table 9, originally obtained as mosaic units from Maine. It is again clearly evident that the differ-

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CORRELATION OF EXPERIMENTAL RESULTS WITH THE MOSAIC INCIDENCE IN COMMERCIAL FIELDS

The results obtained under control conditions and in the previous field experiments justify the question as to the effect of environmental conditions on the selection of seed potatoes being shipped to the South. While it has been generally observed that these diseases are much more serious in the South, no published data are at hand comparing the growing conditions of the South with those of the northern seed producing states. It has always been evident that seed sent South contained a higher percentage of degeneration diseases than was reported in the northern fields from which the seed was obtained. This was often attributed to aphid transmission late in the season in the North resulting in a higher percentage of disease in the progeny. The problem in Nebraska, that is, the increase of mosaic both in our northern plantings as well as in the plants grown in the South, could not be explained on this basis, inasmuch as aphids are very rare in the dry land sections of the West.

In 1920, 1921, and 1922, the author in many observations could not find more than an occasional aphid present in a very small number of the fields inspected. In 1923, the high rainfall was assumed to be more favorable for an infestation, and a close inspection of fields was made.

The author personally inspected about 2,000 acres of dry land potatoes and was unable to find more than a trace of aphids. A survey[1] was made of 18 fields in Scotts Bluff County, 10 of which were irrigated. Eight of the 10 irrigated fields contained aphids on 18 per cent of the plants. Seven of the 8 dry land fields in the same locality contained aphids on 4 per cent of the plants. In all cases, only one or two aphids were present on a plant.

Inasmuch as all seed now certified in Nebraska and most of the general seed crop are grown under dry land conditions, the small number of aphids present in what can be considered the most favorable year for an infestation, would hardly account for any considerable increase in the percentage of mosaic.

The following record obtained from the certification records of the Horticultural Department, Nebraska Agricultural College, and from reports from Mr. G. L. Tiebout and Dr. C. W. Edgerton of the Louisiana Agricultural Experiment Station, gives some idea of the amount of mosaic in northern grown seed potatoes when planted in the South.

[1]This survey was made by Mr. William Morrow, Field Assistant.

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The average of mosaic in 4 strains grown in Nebraska in 1921 was 0.4 per cent. These 4 strains tested in Louisiana in 1922 showed 16.0 per cent mosaic. The same seed grown by the same growers in commercial fields of Nebraska in 1922 showed 1.0 per cent mosaic. In the 1923 tests in Louisiana, 11.1 per cent mosaic was reported, while in 1923 the records in Nebraska showed 6.0 per cent mosaic. These differences between Louisiana and Nebraska percentages in the same stock, can be explained by the effect of different environmental conditions on the symptoms of the disease.

A certain number of strains of Bliss Triumphs grown in Nebraska in 1922 were planted at Baton Rouge, Louisiana, and mosaic readings were made by Mr. H. O. Werner of the Horticultural Department of the Nebraska College of Agriculture, on April 23, 24, 1923. The following table shows the average percentage of mosaic per field in the commercial fields in Nebraska in 1922, in the Louisiana tests in 1923, and in the commercial fields grown from the same seed in Nebraska in 1923:

Number of strains	Nebraska 1922 *Per cent*	Louisiana test 1923 *Per cent*	Nebraska 1923 *Per cent*
40	1.0	5.8	4.0
32	1.5	16.9	....

Some of the lots tested in Louisiana showed enough mosaic to discourage their planting again in Nebraska and these fields were listed separately. These tests show not only the effect of climatic conditions on the visibility of mosaic symptoms, but also the use to which such a test can be put in eliminating undesirable lots. It must also be noted that the Louisiana readings include all plants grown in the test plots while the readings in the commercial fields of Nebraska would be influenced by roguing. In 1922 most of the roguing was done after the mosaic readings were made so that the visible mosaic in the strains planted in both Louisiana and Nebraska in 1923 had been removed. In 1923 a considerable amount of mosaic had been removed from the fields before the mosaic readings were made. These facts would tend to increase the differences shown in the above table.

Considering now the conditions under which these crops were grown, we find a marked correlation between the weather conditions and the amount of visible mosaic.

In figure 2 the mean weekly temperatures for comparative weeks of different potato sections of the country are plotted. For this purpose a 2-month period was taken covering the time from the emergence of the plant to the time the foliage is fully developed. These periods may not be exactly comparable, but

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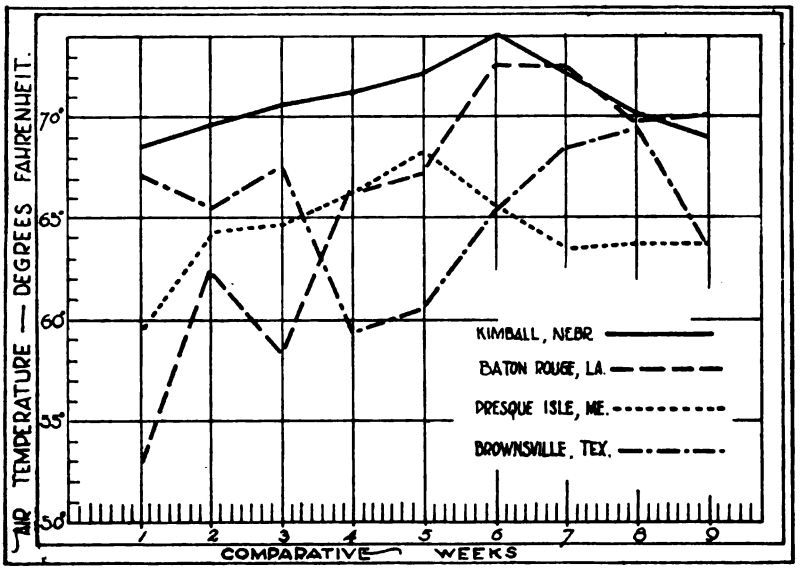

FIG. 2.—Graph showing weekly mean temperatures for comparative weeks of different potato growing sections.

Kimball, Nebraska, June 15 to August 15, six-year average.

Presque Isle, Maine, June 15 to August 15, ten-year average.

Baton Rouge, Louisiana, March 15 to May 15, 1923.

Brownsville, Texas, January 15 to March 15, 1923.

The normal temperatures by months for Baton Rouge and Brownsville are shown in Table 13.

they are close approximations made by a number of observers in the several localities. Mosaic readings are made in Nebraska chiefly in July, while in Louisiana the disease usually appears very marked in April. While the 2-month period shown in figure 2 may extend over a greater length of time than that usually used for the detection of mosaic it is believed to cover the period during which mosaic symptoms would be greatly influenced by external conditions. Further monthly data are presented in Table 13, covering a 3-month period and comparing the 1923 data for Brownsville and Louisiana, from which figure 2 is composed, with the normal monthly mean for those localities.

It can be easily seen that Kimball, Nebraska, temperatures are consistently higher than the others and for 6 weeks are above 70° F. It is also true that these diseases are usually severe at the 2 southern points and in Maine and this can be directly correlated with the lower temperatures occurring in those localities.

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TABLE 13.—*Normal monthly mean temperature, precipitation, and sunshine for comparative months in different potato sections*[1]

Comparative months	June July August Kimball, Nebr.		March April May Baton Rouge, La.		Jan. Feb. March Brownsville, Tex.		June July August Presque Isle, Me.	
	TEMPERATURE °F.							
	Normal	*1923*	*Normal*	*1923*	*Normal*	*1923*	*Normal*	*1923*
1.....	65.3	64.2	61.0	58.6	48.4	56.4	59.8	59.2
2.....	71.1	72.6	66.9	67.9	50.3	49.1	66.1	62.4
3.....	69.7	67.6	73.8	72.5	68.4	65.0	63.1	58.8
	PRECIPITATION							
1.....	2.3	4.7	4.51	6.3	1.75	1.8	3.9	0.8
2.....	2.3	2.4	4.72	6.2	1.80	4.5	3.3	4.3
3.....	1.7	3.5	4.33	8.0	1.23	1.3	3.2	2.3
	DAYS CLEAR (AND PARTLY CLOUDY)							
1	17 (10)	13 (13)	.....	12 (7)	.....	17 (6)	14 (10)	21 (6)
2.....	13 (16)	10 (20)	.....	12 (8)	.....	7 (5)	16 (8)	16 (6)
3	15 (14)	12 (16)	.....	13 (13)	.....	8 (15)	16 (9)	15 (11)

[1]Normal temperatures and precipitations for Kimball, Baton Rouge, and Brownsville are calculated from the departures from normal given by the U. S. Weather Bureau Monthly Records for 1923. Normal and clear days for Kimball were compiled from 6-year records. The data for Maine were obtained thru the courtesy of Dr. Folsom of the Maine Agric. Expt. Station. These data are from 8 to 10 year records in every instance.

The usual assumption that southern potatoes do not make good seed because of the high temperatures at which they are grown would apply, in the early crop at least, only to the period during which tuber formation takes place. At both Brownsville and Baton Rouge the temperature increases rapidly during the later stage of growth, while it decreases in Maine and Nebraska; this would be even more evident if the last month of the potato season were shown.

If we compare the temperatures for the months in the various sections during which mosaic determinations are usually made, *i. e.*, from the third to the sixth week inclusive as shown in figure 2, it will be seen that there is considerable difference in the temperatures. It is also evident from Table 13 that no clear cut correlation can be made between mosaic and rainfall or even sunshine. Rainfall, however, is here considered only for the

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be undertaken here. It is clearly evident, however, that low temperatures are necessary for the appearance of mosaic symptoms and that the mean temperatures in the southern states and in Maine are much lower than for the corresponding periods of growth in Nebraska. The point used to represent temperature conditions in Nebraska, *i. e.*, Kimball, has even a lower mean temperature than other seed potato producing sections of western Nebraska.

A complete study of the problem, however, must also take into consideration the effect of these factors on plant growth. It is true that the number of clear days is not greatly different in these different sections, as shown in Table 13. If we would consider the intensity of sunlight, however, it would be found that the Nebraska fields are subjected at their high altitude to a very intense sunlight which usually causes all the leaves to droop in midday and this factor in combination with high temperatures usually decreases the visibility of mosaic symptoms.

The records here shown explain very well the differences in the readings of mosaic in Nebraska and Louisiana as previously noted. The correlation shown for widely different locations can also be made for different seasons in the same region. The difference in the amount of mosaic present in the commercial fields in Kimball County, Nebraska, in 1922 and 1923 was considerable as is shown by the following table:

Year	No. of fields	Total acreage	Average percentage of mosaic per field
1922	44	607	0.6
1923	75	1333	3.0

About 70 per cent of the fields in 1923 were planted with seed from the 1922 crops. In 1922, no fields were rejected in this county on account of mosaic; while in 1923, 13 fields were rejected, and averaged 8.0 per cent mosaic.

In 1922 no aphids could be found and they were very scarce in 1923, so the increase of disease could hardly be attributed to aphid transmission.

If the weather conditions are considered, it is very plain that these results were not caused by aphid transmission, but that what probably occurred was a masking of the symptoms in 1922, thus preventing successful roguing and seed selection. An examination of figure 3 will show that the mean weekly temperatures for 1922 were above 70° F. for the greater part of the season. The temperatures were highest during the period when inspections are usually made in the fields. In 1923 the mean temperatures were consistently below 70° F. A comparison of

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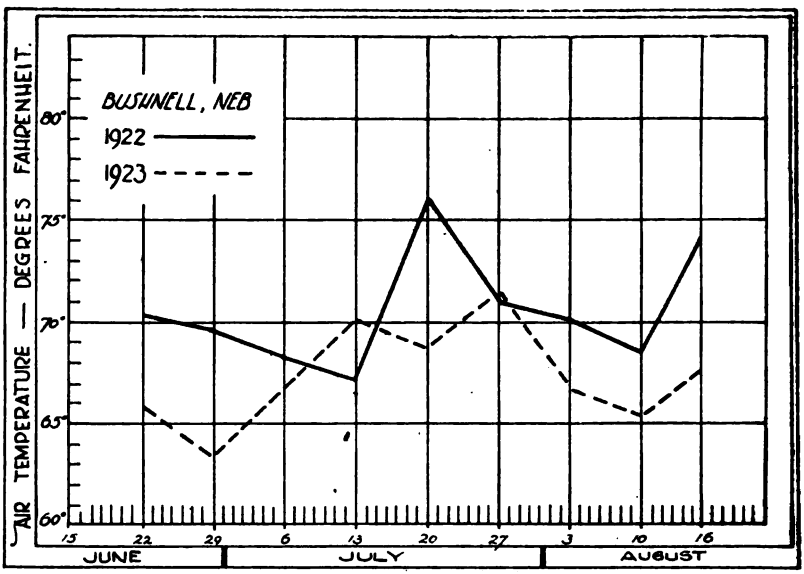

FIG. 3.—Graph showing weekly mean temperatures in Kimball County, Nebraska, for 1922 and 1923. Records taken at the farm of August Gadeken, Bushnell, Nebraska. Means obtained from 2-hour readings for each week.

rainfall and sunshine shows an increase in the precipitation for 1923 over that of 1922, and a considerable decrease in the number of clear days as tabulated below:

	June		July		August		Total	
	1923	1922	1923	1922	1923	1922	1923	1922
Clear days	13	22	10	15	12	18	35	55
Rainfall, *inches*	4.70	2.08	2.48	1.08	3.55	1.66	10.73	4.82

The same reaction evidently occurs in other sections as shown by the data in Table 14, obtained from Dr. Folsom of the

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TABLE 14.—*Relation of weather to the appearance of mosaic symptoms at Presque Isle, Maine in* 1921 *and* 1923 [1]

	Mean temperature		Precipitation		Clear	Partly cloudy	Clear	Partly cloudy
	1921	1923	1921	1923	1921		1923	
	°F.	°F.	*In.*	*In.*	*No.*	*No.*	*No.*	*No.*
May.....	53.4	46.5	1.63	1.58	17	10	14	10
June.....	58.8	59.2	1.58	0.82	13	7	21	6
July.....	71.8	62.4	2.49	4.32	19	5	16	6
August...	60.8	58.8	5.43	2.32	15	8	15	11
Sept.....	56.3	54.1	3.15	2.98	16	6	20	4

[1] 1921—Poor mosaic symptoms; 1923—good mosaic symptoms.

May and low precipitation in May and June. This, however, followed a winter of heavy snowfall and the ground was very wet in May. Good mosaic symptoms appeared in 1923 and were correlated with low temperatures in July and August.

DISCUSSION

It has been shown that under control conditions high temperatures (above 70° F.) seriously decrease the visibility of mosaic symptoms. The same effect has been observed in field experiments and in commercial fields. The mottling of mosaic leaves is decreased by high temperature and the addition of intense sunlight eliminates this symptom. High temperatures tend to produce a smoother leaf, thus masking the symptoms of wrinkling, curling, rolling, and rugosity. High soil moistures apparently favor the appearance of such leaf symptoms. It must be remembered, however, that under average field conditions in Nebraska, increased rainfall usually is accompanied by decreased temperatures and sunlight. When all 3 factors are controlled, temperature appears to have the greatest influence.

Field experiments have shown that a short period (4 to 8 days) of high temperature with intense sunlight, eliminates the symptoms of mild mosaic. The symptoms are more affected by environmental conditions during the early growth of the plant and the effect decreases with age. The more severe types of

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mosaic do not react as rapidly or completely to external conditions as the milder types. The date of planting in the same locality resulted in a wide divergence in the amount of visible mosaic at any specified date.

Taking all these factors into consideration, it must be admitted that there will necessarily be a large error in field readings made without regard to these factors. To make an accurate estimate of the amount of mosaic in a field, it becomes necessary to consider the date of planting and the environmental conditions under which the plant has been growing, particularly with reference to the period immediately preceding the examination. Determination of mosaic should not be made on very young plants unless under the most favorable conditions, as the symptoms will be masked more rapidly than on slightly older plants. Roguing to be complete should be done only during periods when the appearance of the symptoms of the disease is favored by climatic conditions.

It has been shown that these results not only can explain to a large extent the variations in mosaic readings during any one year in a particular field, but also the changes occurring during several seasons in the same locality or even the apparent increase in mosaic occurring when "northern grown" seed from the western states is planted in the southern states.

The examples shown in the southern states, *i. e.*, Baton Rouge, Louisiana, and Brownsville, Texas, indicate that the temperatures prevailing there, as in Maine, are normally low enough during the early season to favor the appearance of mosaic symptoms. The reverse is true for Nebraska and probably a considerable area in the West. The low temperature in the South during the early period of growth is often followed by extremely high temperatures during the period of tuber formation, thus greatly decreasing their yields.

In Nebraska, there are indications that mild mosaic does not materially decrease the yield. However, accurate percentages of this type are difficult to obtain because of the rapid masking of symptoms. Combinations of this type of mosaic with spindle-tuber would occur in the fields and would reduce the yields ma-

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ditions that were more favorable for the appearance of the symptoms. This complicates the problem and makes it impossible to detect any particular disease type with certainty, under field conditions, even when insect transmission is eliminated.

While mosaic symptoms are more evident with early planting and lower temperatures, the reverse appears to be true for spindle-tuber. Spindle-tuber and combinations of spindle-tuber with mosaic result in a greater decrease in yield than mosaic alone.

In the opinion of the author, the effect of the high temperature, low rainfall, and intense sunlight in certain areas of the West is of as great importance as aphid transmission. They are often the chief factors responsible for the apparent increased amounts of mosaic in our seed stock, the masking of the symptoms preventing good results from roguing and seed selection; and of these factors temperature is the most important.

Further work is greatly needed in the West for the proper understanding of this problem, which in most of its aspects is considerably different from those in the eastern states. This is true regarding the environment, the varieties being grown, the number of aphids present and the possible presence of other insect carriers of the disease as well as the native plants which may be possible over-wintering hosts. The work reported in this publication is preliminary in nature and is being followed by further studies on the effect of temperature, moisture, and sunlight.

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Potato Wilt and Stem-End Rot Caused by Fusarium Eumartii

R. W. GOSS
DEPARTMENT OF PLANT PATHOLOGY

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Potato Wilt and Stem-End Rot Caused by Fusarium Eumartii

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SUMMARY

1. The cause of potato wilt and stem-end rot in Nebraska was found to be *Fusarium eumartii*, an organism not previously reported from Nebraska.

2. The disease was found widely distributed in the commercial potato sections of the state, and has evidently been present for many years.

3. The disease was found to be one of the most serious occurring in the older potato sections in western Nebraska.

4. The symptoms and distinguishing signs of the disease were determined and are presented on page 12.

5. The disease results in decreased germination of infected seed tubers, wilt and barrenness of infected plants, decreased yields both total and marketable, and a high percentage of stem-end rot tubers. This tuber infection may increase and do great damage in storage. Such tubers are also easily invaded by secondary parasites which enter thru the infected tissue at the stem end.

6. Isolation studies showed that the organism could usually be recovered from the roots of infected plants. It could also be isolated from the lower stem unless the disease was far advanced and secondary invaders were present. Discolored tissue in the upper stem was always sterile. The organism could be recovered from stolons and infected tubers still attached to the plant except from the most advanced portions of the discolored tissue which were usually sterile. Infected tubers in storage usually contain a large number of rapidly growing secondary parasites which overgrow the causal organism which is a slow grower, and make its isolation difficult. Isolations to be dependable should be made from material fresh from the field and preferably from the roots, rather than from stored tubers.

7. The examination of both free hand and paraffin sections of infected plants showed that the organism does not invade the xylem vessels to any great extent and that wilt is not due to a blocking of these vessels by the growth of the organism. In the roots the cortex was chiefly infected while the organism was seldom found in the vascular cylinder. The organism reaching the stem from the root chiefly invades the cortex and may eventually penetrate all the stem tissues. A necrosis of certain cells accompanied by the presence of a dark staining granular substance both inter and intracellular, and

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8. In liquid cultures it was determined that the organism produces a thermolabile toxic substance capable of causing the wilt of potato tops placed in the filtrate, in from 30 minutes to 2 hours. It is believed that this substance, in addition to other toxic substances probably produced by the decay of the host tissue, may be partially responsible for the wilting of infected plants.

9. It was also found that a thermolabile toxic substance was produced in liquid media, which was capable of causing maceration of potato tuber tissue in 2 to 5 hours. This substance is probably responsible for the discoloration and decay of the host tissue in advance of the organism.

10. Growth-temperature studies of the organism in Petri dish cultures were made. The optimum temperature for growth was 25°, the maximum 33°, and the minimum 5° C. The organism grows very slowly even at the optimum temperature.

11. The organism was capable of growing in media having a range of H-ion concentration from pH 4.5 to pH 8.5. The reaction of the medium had no appreciable effect on growth at the optimum temperature. Growth was slightly retarded at the maximum and minimum temperatures with a very acid or very alkaline medium.

12. Pathogenicity studies showed the organism to be a very virulent parasite capable of producing a rapid wilt of the plant and a stem-end rot of the tuber. One hundred per cent infection was usually obtained by both soil and seed inoculations except at extremely unfavorable temperatures.

13. The optimum soil temperature for the disease under control conditions with both soil and seed inoculation was 20° to 25° C. Infection could not be determined at temperatures above 30°. Slight infection occurred at 12°.

14. Soil moisture had very little effect on infection, as 100 per cent infection occurred with all moisture contents used with both soil and seed inoculation. After infection the symptoms appeared first and the resulting number of infected tubers was greatest with high moisture contents. After the first appearance of the disease the symptoms of wilt progressed most rapidly at the low moisture contents. Abundant soil moisture prevented severe wilt even when practically all the roots were infected.

15. Seed infection resulted in a slow progress of the disease up the stem and sometimes out into the roots. Soil infection resulted in a rapid progress of the disease thru the roots and after reaching the stem the discoloration of the vascular system often progressed downward into the healthy seed piece. Infection of 2 or 3 roots was enough to cause this discoloration of the seed piece which might easily be mistaken in the field for seed piece infection.

16. Field experiments showed that the amount of disease resulting from inoculated seed could be correlated with the environmental conditions as previously determined in the greenhouse experiments.

17. The disease was found to be transmitted by stem-end rotted and internally discolored seed. The type of discoloration in the seed could not be correlated with the organisms isolated nor with the percentage of resulting disease.

18. Infested soil was found to be one of the chief sources of inoculum. Healthy seed on infested soil yielded about the same as infected seed on non-infested soil.

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19. Tuber inoculations at different temperatures and relative humidities showed that storage rot could be held in check at temperatures below 10° C. Temperatures above this point increased the extent of tuber rot. Temperature was found to be a greater factor than the relative humidity in relation to storage rot.

20. The organism is not capable of penetrating the sound epidermis of a mature tuber.

21. The disease can be controlled partially by the selection of healthy seed and the use of long rotations on infested soil, or by the use of new potato soil. The amount of stem-end rot in the tubers can be reduced by digging infected fields before tuber infection has occurred. The storage rot can be held in check by temperatures below 10° C. with a relative humidity as low as can be maintained without causing serious shrinking.

22. A comparison of *Fusarium eumartii* and *F. oxysporum* and the diseases they produce is presented on page 23.

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Potato Wilt and Stem-End Rot Caused by Fusarium Eumartii

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INTRODUCTION

The causal relation of *Fusarium oxysporum* Schlect. to a wilt and tuber rot of potatoes has previously been investigated by the author and the results have been published (6). It was found impossible to produce the typical disease with this organism consistently. A critical review of the literature showed the same lack of experimental proof in the work of other investigators. The author therefore concluded that *F. oxysporum* was not a very virulent or destructive organism but rather a soil saprophyte capable of becoming weakly parasitic under conditions unfavorable for the host plant. The reports of losses caused by this organism were considered to be greatly exaggerated owing to confusion with other troubles.

When the author came to Nebraska in 1920 he was greatly surprised to find that in certain of the older potato growing sections of the state, potato wilt and stem-end rot, presumably caused by *Fusarium oxysporum*, was undoubtedly the most serious disease present. It was not uncommon to find fields with 50 per cent of the plants infected. Certain symptoms of the disease, notably the earliest symptoms on the foliage and the characteristic stem-end rot of the tubers, along with other detailed symptoms to be pointed out later, did not agree with the symptoms of wilt caused by *F. oxysporum* as the author had observed it elsewhere both in the field and as a result of experimental infection studies.

Isolations from wilted plants and stem-end rot tubers were made in large numbers. Many cultures from infected tubers were sterile. *Fusarium oxysporum* along with other *Fusarium* species, however, were often obtained. Infection experiments with these organisms always failed to produce the typical disease.

This work was continued, however, and in February, 1921, isolations from a stem-end rot tuber yielded a species of Fusarium different from any previously isolated. Infection experiments proved it to be a very virulent parasite capable of producing the characteristic wilt of potato plants and later tests resulted in the typical stem-end rot tubers produced by

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infected plants. By means of cultural studies the organism was identified as *Fusarium eumartii* Carp. This species had not been previously reported from Nebraska.

A review of the literature showed very little experimental work with this organism. The description of the disease, however, indicated a disease similar to that found in Nebraska. The present study was therefore undertaken to obtain more information regarding the pathogenicity of *Fusarium eumartii* and to compare its action with *F. oxysporum*, in order to distinguish between and to determine the relative importance of the diseases produced by these two organisms. An effort was also made to explain the many negative results of isolation studies reported by various investigators, as well as the inconsistent results often reported in studies of the transmission of wilt by infected tubers. Investigations dealing with the effect of certain environmental conditions on the occurrence of the disease were also undertaken. All of the experiments recorded in this publication were conducted with the Bliss Triumph variety.

It is hoped that the results presented here will materially assist in clearing up some of the long disputed points concerning the wilt of potatoes, and open up a new line of investigation in the study of the action of these wilt-producing organisms and their control.

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PART I

THE DISEASE

HISTORY

The first description of the disease in the tubers and the identification of the causal organism was published by Carpenter (1) in 1915. He refers to it as a previously undescribed field and storage rot observed for the previous 2 years in Pennsylvania. He lists it as a stem-end and wound invader also capable of infecting the lenticels. He does not attribute the wilt of plants in the field to *Fusarium eumartii* but considers this organism to be more likely a secondary invader following wilt caused by *F. oxysporum* or *Verticillium albo-atrum* Reinke and Berthold. No inoculations were reported on plants, but inoculations in tubers proved it to be capable of causing a serious storage rot.

In 1916 Haskell (7) in a preliminary paper reported a disease occurring in New York, causing both a wilt of the plant and a rot of the tuber by an organism "closely related to, if not identical with *Fusarium eumartii* Carpenter."

C. R. Orton (10), who furnished the material for the studies made by Carpenter, described the disease briefly as it occurred in Pennsylvania. He noted that the "stem-rot" may follow "wilt" but he did not state whether or not he believed them to be due to the same organism. He noted that it was a very serious storage rot of potatoes. No inoculation experiments were reported.

Haskell (8) gave the most complete description of the disease till then published and identified *Fusarium eumartii* as the organism mentioned in his previous note. He reported inoculation experiments by both stem inoculation and soil inoculation and his results showed that the organism was capable of causing both a wilt of the plant and a stem-end rot of the tuber. He also reported tuber inoculations showing the organism to be a wound parasite. His description of the disease fits very closely the symptoms occurring in Nebraska. The results of his inoculation experiments have been repeatedly duplicated on a larger scale by the author, and the disease described in this paper is apparently identical with that described by Haskell.

Edson and Shapovalov (3) reported a few inoculations made by placing cultures of *Fusarium eumartii* in contact

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with the lower stems of potato plants. Serious stemrot, deep stem cankers, and lesions on the roots and stolons resulted from these inoculations. All the inoculations resulted in infection. No aboveground symptoms were reported.

DISTRIBUTION

The disease has not been reported as being very widespread in the United States. The first reports of the disease were from Pennsylvania and New York as noted above. Since 1916 it has been reported[1] from 3 counties in New York, from at least 16 counties in Pennsylvania, and from 5 counties in Ohio. The disease was first reported from Nebraska by the author (5) in 1923. The widespread occurrence of the disease in a severe form in western Nebraska in both the dry land and the irrigated sections would indicate that it has been present for some time. As far as the author is aware this is the first report of the disease west of Ohio. It is reasonable to suppose, in the light of the investigations herein presented, that the disease is also present in other western states.

ECONOMIC IMPORTANCE

Very little information is available on the amount of damage due to this organism. Carpenter (1) reports the disease as being a storage rot of considerable importance in Pennsylvania, sometimes causing losses of 50 per cent from dry rot of the tubers. This statement is corroborated by Orton (10).

In Nebraska the disease is considered second in importance only to spindle-tuber and mosaic, and is probably of greater importance than mosaic in many of the commercial fields in western Nebraska not being grown for seed purposes. The disease has been found to be more serious in the

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4500 acres were inspected in 1922 and over 5500 acres in 1923. The author personally examined about 100 of the fields inspected in 1923.

TABLE 1.—*Occurrence of Fusarium wilt and stem-end rot in western Nebraska*[1]

Time of inspection[2]	Number of fields	Number of fields infected	Av. amount of infection in infected fields	No. of fields rejected for certification because of Fusarium wilt	Av. amount of infection in rejected fields
		Per cent	*Per cent*	*Per cent*	*Per cent*
			1922		
First—field....	256	78.5	1.4	6.6	6.1
Second—field...	204	76.4	4.6	19.1	16.3
Third—bin.....	157	82.8	3.8	12.7	14.4
			1923		
First—field....	346	10.6	1.0	0.8	3.4
Second—field...	193	61.1	1.4	5.1	7.7
Third—bin.....	148	35.8	3.2	6.0	23.7[3]

[1]These data were obtained from fields for which applications for certification had been made.
[2]First inspection was made from July 25 to August 20 in 1922 and about one week earlier in 1923. Second inspection early in September, and third as early as possible in the bins.
[3]Two of the 9 fields from which this percentage was obtained contained about 50 per cent infection, thus making the average abnormally high.

The amounts of infection shown in Table 1 are of course much smaller than the average infection for commercial fields, owing to the better grade of seed usually planted when the crop is grown for seed certification. It is evident that the amount of infection varies greatly from year to year in the same locality, and also that the disease is not usually visible in appreciable percentages until late in the season. The number of infected fields and the percentage of infection per field was much greater in 1922 than in 1923, due in a great measure to the more favorable temperature for the disease as will be more fully discussed later.

The disease percentages in Table 1 are based both on the amount of wilt in the field and on the percentage of infected tubers. The disease may also cause considerable damage by decreased germination and increased barrenness of plants. The extent of this type of damage is more difficult to determine by other than experimental methods.

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The data in Table 1 include all wilted plants and all stem-end rot or vascular discolored tubers and no attempt is made to distinguish between the damage caused by *Fusarium eumartii* and the possible damage caused by *F. oxysporum*. As a result of a three years' study of the problem in Nebraska and previous investigations with *F. oxysporum* elsewhere, the author believes that probably 95 per cent of the wilt and stem-end rot occurring in the large commercial fields of Nebraska is due to *F. eumartii*. In fact the reported losses due to *F. oxysporum* previously made by the writer (6) probably included to a great extent the disease caused by *F. eumartii* as noted at that time.

The importance of the disease varies locally and in some sections is the most serious disease present, causing very serious losses both in the field and in storage.

DESCRIPTION

The symptoms of this disease as in other wilt diseases are found to vary under different environmental conditions. There are, however, certain well marked characteristics that serve to distinguish this disease from others with which it might easily be confused.

On the vines:—The first symptoms of the disease on the foliage are the appearance of small light green areas between the veins of the leaflets, giving them a mottled appearance; these areas gradually turn yellow. This is often accompanied by a bronzing of the upper surface of the leaf in smaller irregular spots. These first symptoms are easily detected after they are once associated with the disease. The rapidity of the development of the symptoms on the foliage is greatly influenced by the extent of infection in the roots and stems and by the rate of transpiration and the available soil moisture. If the soil moisture content is high the foliage symptoms may never advance to the wilting stage. Under such conditions with severe attacks the leaves may show a yellowing, rolling and rosetting, sometimes accompanied by the development of aerial tubers and other symptoms which

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veins, and petioles which is observable at the surface. Under dry conditions the wilt may progress rapidly and the plant be completely killed in a short time. If drought occurs after previous high moisture, the rosetted tops described above may dry out and the leaves still remain tightly rolled after the entire plant is dead.

On the roots:—When infection has taken place thru the roots, the root hairs and fine roots will often be completely destroyed, (Plate 7, A). Under moist conditions the cortex of the affected roots is easily sloughed off. Under dry conditions the affected roots are brittle and break off easily. When infection has occurred from or thru the seed piece, the disease often progresses out from the stem into the roots, in which case the above symptoms are observed at the base of the roots, while the tips and smaller root hairs may be healthy.

Stems:—If infection occurs from or thru the seed piece, the first signs of disease are at the base of the stem. The disease is not confined to the vascular system and often the entire basal portion of the stem sometimes up to the surface of the ground is completely destroyed (Plate 7, B). Under wet conditions it appears somewhat similar to black-leg except that the color is a dark brown instead of black. If drought follows previous high moisture the whole basal portion of the stem dries up and shatters.

When infection occurs thru the roots, the disease works both up and down the stem from the point of infection, that is, from the base of the infected roots. In this type the browning is most conspicuous in the vascular region, but gradually extends thru the pith cells, appearing as a light brown discoloration. The discoloration may extend down to the base of the stem and even into the healthy seed piece, producing a vascular discoloration in the seed that would lead a person who dug up such a plant to believe that infection had taken place from the seed piece (Plate 6, B).

In both the above types of infection, the disease, after

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Stolons:—From the stem the disease works out thru the stolons to the tuber. If the epidermal tissue of the stolons is removed, a brown discoloration of the remaining tissue is evident, which is sometimes confined to the vascular elements, but in severe attacks the entire stolon may be completely rotted.

Tubers:—Tuber infection in the field always occurs thru the stolon. The common symptom on the tubers under western Nebraska conditions is a dark discoloration of the surface at the stem-end, with the affected stolon often remaining attached. The area showing the discoloration gradually becomes sunken, with a slight wrinkling of the tissue at the edges. As the disease progresses, a greater portion of the tuber shows the same appearance, but this rarely exceeds more than one-quarter of the tuber. Sections of such affected tubers show a variety of internal symptoms, which can be roughly grouped as follows: 1—Stem-end rot, with no vascular discoloration; in this type there is a sharp line of demarcation between healthy and infected tissue (Plate 2, A, B). 2—Stem-end rot with vascular discoloration (a) accompanied by a soft rot of the adjacent tissue forming a band of light brown tissue from 5 to 10 mm. wide which sometimes extends the entire length of the tuber; (Plate 1, B, C, D, F),—this is the most common type; (b) the discoloration in advance of the stem-end rot may appear as a black network or sometimes a brown flecking of the tissue, found most prominent in the vascular region but not entirely confined to it (Plate 1, A); (c) the vascular browning may be a very light brown discoloration entirely confined to the vascular region (Plate 1, E), similar to the type of discoloration more often produced by *Fusarium oxysporum*. The above types of vascular discoloration may all occur in the absence of any stem-end rot.

These symptoms have all been found in tubers produced

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In severe cases such eye infection can be seen externally. The disease increases in storage, unless temperatures below 10° C. are maintained. Such increase is also favored by high relative humidity. The disease also causes serious damage in stored tubers by the action of secondary invaders such as *Fusarium trichotheciodes.*

THE CAUSAL ORGANISM

Identity and Description

In a previous report the author (5) expressed the opinion that the organism isolated in Nebraska in 1921 and which was capable of producing the wilt and stem-end rot of potatoes was *Fusarium eumartii.* Further studies have substantiated this view.

This organism has been found to be practically identical[1] with *Fusarium eumartii* as described by Carpenter (1). Certain minor differences regarding septation and size of conidia have been observed. The following brief summary of many observations of the organism in pure culture from single spore isolations is therefore presented.

Fusarium eumartii:—(Type from culture No. 64 used in the present investigation, isolated from stem-end rot potatoes produced by a wilted plant). Conidia nearly straight in lower half, slightly curved in upper half, of nearly even diameter thruout, apex rounded, basal cell ventrally depressed, slightly pedicellate. Conidia 4 to 6 septate with 5 septate conidia greatly predominating, averaging 50 to 60 x 5 to 7 u. on a 2 per cent agar medium not too rich in sugars. Seven septate conidia rare. Aerial mycelium weak to well developed. Conidial masses vary from light brown to deep blue green and dark mixed colors. Zonation occurs on oat agar, the color being light brown when young and later becoming dark green, sporodochia usually abundant. On soft agars, the plectenchymatic stroma is weakly developed or lacking and pionnotes cover the surface of the substratum. Microconidia typically present on aerial mycelium, mostly O

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Cultures on potato plugs 14 days old.

Aerial mycelium sparse, 1 to 2 mm. high, white, changing to green near the substratum. Sporodochia light brown in color, microconidia 1.5 per cent, macroconidia 98.5 per cent.

3 septate, 10 per cent, 30.7x2.5 u. (25–35x1.7–3 u.)
4 septate, 25 per cent, 34.0x3.7 u. (27–42x2.5–4 u.)
5 septate, 60 per cent, 38.0x3.7 u. (32–47x2.5–5 u.)
6 septate, 3.5 per cent, 45.0x4.2 u. (41–47x3.7–5 u.)

Cultures on 2 per cent nutrient agar, 15 days old.

Pseudopionnotes vinaceous blue, no aerial mycelium. Microconidia rare.

Macrocondia, 1 septate, 0.5 per cent, 15.0x2.5 u.
2 septate, 1.0 per cent, 29.7x4.3 u.
3 septate, 19.0 per cent, 33.2x4.6 u. (27–37x3.7–5 u.)
4 septate, 26.5 per cent, 34.7x5.0 u. (32–37x3.7–6 u.)
5 septate, 52.0 per cent, 38.5x5.0 u. (34–42x3.7–6 u.)
6 septate, 1.0 per cent, 42.5x5.0 u.

Cultures on 2 per cent oat agar, 70 days old.

Aerial mycelium sparse, light brown. Numerous dark green sporodochia on surface of the substratum arranged in concentric zones. Microconidia rare.

Macroconidia, 1 septate, rare.
2 septate, 1.0 per cent, 26.2x4.2 u.
3 septate, 6.0 per cent, 34.7x5.2 u. (23–46x3.5–7.0 u.)
4 septate, 12.0 per cent, 49.0x5.9 u. (41–59x5.2–7.0 u.)
5 septate, 67.0 per cent, 58.1x6.6 u. (42–63x5.3–7.7 u.)
6 septate, 14.0 per cent, 64.0x7.0 u. (56–70x5.4–7.7 u.)
7 septate, rare.

It is evident from the above data that the organism varies considerably under different cultural conditions and that in many instances it does not show as high septation or as large size conidia as described by Carpenter (1). However, the growth of the fungus on oat agar as shown by the above measurements was very similar to Carpenter's original description of the organism. The general cultural characteristics and the type of conidia were the same; therefore the organism here studied is considered to be identical with his *Fusarium eumartii.*

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Physiology

ISOLATION

The causal organism can usually be isolated from the roots of infected plants by the ordinary tissue culture methods. Isolations from heavily infected basal stems often yield miscellaneous organisms, while cultures from the discolored pith which sometimes occurs in the upper stem are usually sterile. The pathogene can often be recovered from infected stolons and from tubers recently removed from such stolons. Cultures from such tubers, however, are usually sterile if the isolations are made from the extreme edges of the discolored tissue as this discoloration occurs in advance of the organism. Isolations from the black or dark brown necrotic tissues, sometimes scattered thru the tuber but usually more severe in the vascular region, are usually sterile. Cultures from infected tubers which have been in storage often yield a variety of tuber rot fungi which are usually more rapid growing organisms than *Fusarium eumartii*. Isolation studies from stored tubers are therefore not a satisfactory basis for determining the presence of the causal organism, and often result in confusion owing to the large number of sterile cultures or miscellaneous fungi usually obtained. Isolations should be made from fresh material obtained directly from the field if dependable results are desired.

GROWTH-TEMPERATURE RELATIONS

The optimum temperature for growth of *Fusarium eumartii* on a 3 per cent potato dextrose agar is 25° C. Slight growth occurs at 5° after 9 days' exposure. Growth occurs at 33° but not at 35°. Exposure to extremely high or low temperatures slightly retards the growth for a few days when the cultures are afterwards changed to the optimum temperature. Intermittent temperatures with 16 hours' exposure at 35° and 8 hours at 25° each day, allow slight growth. On a 3 per cent potato agar there is a great decrease in growth at 30° as compared with that at 25°. This decrease is not so great when 2 per cent potato dextrose agar is used as the medium.

EFFECT OF THE H-ION CONCENTRATION OF THE MEDIUM ON THE GROWTH-TEMPERATURE RELATIONS

Fusarium eumartii is capable of growing under a wide variation in the H-ion concentration of the medium. At the optimum temperature no appreciable difference is evident

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with H-ion concentrations varying from pH 4.5 to pH 8.5 on 2 per cent potato dextrose agar. At the minimum and maximum temperatures for growth there is a slight decrease in the amount of growth at pH 4.5 or at pH 8.5, the maximum growth occurring at a pH of about 7.5.

Pathogenicity

Inoculation experiments of various kinds reported in Part II prove that *Fusarium eumartii* is an extremely virulent parasite capable of causing a wilt of the potato plant and a stem-end rot and internal discoloration of the tuber. Infection can be obtained by seed, soil, and stem inoculations. Such inoculations have always yielded 100 per cent infection except under extremely unfavorable conditions for the disease. The progress of the disease when produced by inoculations is often more rapid than that normally occurring in the field. The typical disease can be produced by the inoculation of 2 to 3 roots.

Life History

SOURCE OF INOCULUM

Fusarium eumartii may live saprophytically in the soil. There are indications that the organism may occur in virgin soils. How long it lives over in heavily infested soils has not been determined. The organism may also live over winter in the seed tuber. Such infected seed when planted will often yield 40 to 50 per cent of diseased plants.

METHODS OF INFECTION

Infection from the soil may occur either thru the roots or thru the seed piece. In Nebraska infection has usually been found to occur thru the roots. The organism chiefly attacks the root hairs and smaller roots, which are often completely destroyed, and it then progresses up into the stem. Such infection results in a discoloration in the stem which may extend down to the seed piece causing a vascular discoloration of the seed piece, as shown in Plate 6, B.

Infection from or thru the seed piece results in a discoloration of the lower stem which may later decay completely. Such infection often progresses out from the stem into the roots for some distance.

In heavily infested soils, infection may occur directly thru the stem, producing a light brown lesion and eventually penetrating thruout the stem.

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FACTORS INFLUENCING INFECTION AND THE PROGRESS OF THE DISEASE

With constant soil temperatures the optimum temperature for infection either from the soil or from the seed piece is about 22.5° and the disease is more severe at 20° than at 25° C. (Plate 3, C). As the temperature decreases, the number of infections and the severity of the disease diminish, until slight infection occurs at 12° and 15°. Similar results occur at temperatures above the optimum, no infection occurring at temperatures above 30°. If infection occurs at the optimum temperature or below, and this is followed by a rapid increase in temperature, the plant wilts very rapidly.

The disease occurs with a wide range of soil moisture contents. The amount of soil moisture apparently does not have any great effect on the amount of infection but it does cause marked differences after infection has occurred (Plate 4). The wilting of the plant is most rapid when the moisture content is low. With high soil moistures the partially destroyed root systems are enabled to take up enough water to prevent the rapid wilting of the plant; the disease, however, continues to progress and often causes a large amount of stem-end rot in the new tubers.

Under conditions of high temperature and low moisture, the wilting of infected plants is very rapid. With low temperatures and high soil moistures the wilting symptoms may not appear and yet the disease may be causing considerable damage.

Factors affecting stem-end rot in storage:— When tubers which have become infected in the field are placed in storage the progress of the disease and the resulting tuber-rot depends greatly upon the temperature and relative humidity of the air in the storage cellar. The disease is favored by high storage temperatures and a high relative humidity (Plate 2). Temperatures below 5° C. completely check the progress of the disease and temperatures below 10° permit only a slight growth even with a high relative humidity; with increasing humidity and higher temperatures the rate of progress of the disease increases. The rotting at the stem-end which often occurs with tubers infected with *Fusarium eumartii* provides a source of entry for other more rapid growing tuber-rot fungi, which often overgrow the real causal organism. *F. eumartii* is not capable of penetrating the sound epidermis of the potato but can gain entrance only thru wounds, or thru the stolon in the field.

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Toxic Secretions of the Organism

IN RELATION TO WILT

Fusarium eumartii when grown in certain liquid media secretes a thermolabile toxic substance capable of causing very rapid wilting of the cut tops of healthy potato plants when they are placed in the filtrate. It is possible that the secretion of this substance in the plant may account in part for the wilting of the plant and also for the killing of the tissue in the upper stem considerably removed from the locus of the organism.

IN RELATION TO TUBER ROT

It has been found that the organism is also capable of secreting a thermolabile toxic substance capable of breaking down the middle lamella of the cell walls in potatoes. It is probable that this action is correlated with the discoloration of the host tissue in advance of the organism as revealed by isolation studies and microscopic examinations.

Relation of the Organism to the Host Tissue

A complete study of the pathological changes in the structure of the host tissue has not been undertaken. However, numerous examinations of infected plants, both by free hand sections and by sections of imbedded material, have brought out certain points regarding the relation of the organism to the host tissue. These examinations have usually been paralleled by isolations from similar portions of the same plant.

It was found that the organism usually penetrated the outer cells of the fine roots (Plate 8, A) and was chiefly present in the cortex. It was not found to be present in the vascular cylinder except in the last stages of the disease when the root was badly decayed. When only the cortex was destroyed complete wilt did not occur, provided the soil moisture was abundant, even tho practically all the roots were infected as the distintegration of the infected cortex allowed the roots

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cortex, but it eventually penetrated all the tissue of the basal stem. Plate 8, C, shows a tangential section of the lower stem at the base of an infected root. The organism penetrating the stem from the infected root was abundant at this point. In this plant the organism could not be recovered in culture or its presence demonstrated by sections at a distance of 5 mm. above the infected roots. Nevertheless, the plant had wilted and an internal necrosis of various tissues had occurred even as high up as the leaves. The tissue first showing necrosis in advance of the organism in the stem has not been determined. Sections made thru the stem about 2 inches above the section shown in Plate 8, C, revealed a necrosis of the younger tissues of the vascular bundles (Plate 9, A, B, C). The presence of the organism at this point and at all points above could not be determined either by cultures or by sections. In Plate 9, A, necrosis is apparent in the external phloem and adjacent cells. The cambium between the xylem and the external phloem also appears to be affected and the amount of cambium is less extensive than occurs in a normal plant. The large heavy-walled cells of the xylem are apparently not greatly affected. In Plate 9, B, another bundle from the same section is shown in which the xylem elements with the adjoining cells and intercellular spaces show the presence of the dark staining granular substance and deep staining cell walls. The other bundle in this section (Plate 9, C) shows this necrotic condition confined largely to the external phloem. Tangential sections made about 6 inches above this point reveal a similar necrotic condition of the pith cells (Plate 9, D). The vascular bundles at this point showed no signs of disease. The necrosis of the pith occurred for a distance of 12 inches above the ground and was more severe at the nodes, where the central pithy cylinder was entirely disintegrated and stained a deep brown color. The granular substance so often found in the necrotic cells and in the intercellular spaces stained a deep green with Pianeze's stain while the surrounding healthy cells stained red. With Delafield's haematoxylin and erythrosin, these necrotic cells took a deep brown or sometimes a golden yellow stain.

Sections of affected stolons showed a necrosis of the same tissues as occurred in the stem. The penetration of the stolon by the organism, however, usually showed the mycelium to be more abundant in the cortex and it was rarely found in the vascular bundles even tho necrosis was apparent.

Sections of affected tubers showed the same appearance of necrotic tissues in advance of the organism. Necrosis was

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usually most abundant in the vascular bundles and surrounding tissues. Plate 8, D, shows a transverse section of a tuber which showed a slight stem-end rot and vascular discoloration with a soft, watery appearance of the adjacent cells. The organism could not be isolated from the tuber but it was isolated from the stolon. Examination of sections of the tuber did not reveal the presence of the organism but showed the typical necrosis pictured in Plate 8, D.

It was therefore evident that the host tissue was killed for a considerable distance in advance of the organism. The results of isolation studies presented on p. 33 also substantiate this fact. It was also evident that wilting of the plant is not caused by the growth of the organism blocking the xylem tubes.

CONTROL

Inasmuch as the disease is transmitted both in the seed and thru the soil, the only practical control method is the use of healthy seed and non-infested soil. Infected seed can be eliminated by discarding all tubers not perfectly sound. It is possible that healthy tubers which have been stored with infected tubers might carry the organism on the surface. The small amount transmitted in this way would be controlled by the usual seed treatments for scab and Rhizoctonia. Long rotations should be used if land has produced a crop of potatoes seriously affected with the disease. Infected seed tubers on non-infested soil give rise to about the same amount of disease as healthy tubers on infested soil. While the organism may be present in soils not previously planted to potatoes, the amount of infection on such soils is usually much less than occurs on old potato soil. New potato land should therefore be used when possible. The use of new potato land is entirely practical in many of the new potato growing sec-

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COMPARISON OF FUSARIUM EUMARTII AND F. OXYSPORUM AND THEIR EFFECTS ON POTATO IN NEBRASKA

THE ORGANISM

Fusarium eumartii Carp.	*Fusarium oxysporum* Schlect.

TEMPERATURE RELATIONS

Optimum 25°, maximum 33°, minimum 5° C.	Optimum 25° to 30°, maximum 37.5°, minimum 5° C.

RATE OF GROWTH IN ARTIFICIAL MEDIA

Slow growth. Diameter of colony on potato agar in 6 days, 38 mm. at optimum temperature.	Rapid growth. Diameter of colonies on potato agar in 6 days, 90 mm. at optimum temperature.

THE DISEASE

ECONOMIC IMPORTANCE

Serious, causing 85—95 per cent of the wilt and stem-end rot in Nebraska. One of the most serious diseases especially in the older potato growing sections of western Nebraska.	Slight, causing not more than 10 per cent of the wilt in Nebraska, and practically no stem-end rot. Minor disease.

DESCRIPTION

On Foliage

Light green mottling accompanied by an irregular bronzing of upper leaf surface. Leaf slowly turns yellow under dry conditions. Leaf dropping in severe attacks with leaf hanging to stem by thread. Final complete wilt. Rolling and rosetting of foliage under moist conditions.	Yellowing around margins of lower leaves, gradually involving entire top, with final complete wilt.

In Roots

Destruction of root hairs and fine roots. Brittle under dry conditions. Cortex sloughs off under wet conditions.	Similar to *Fusarium eumartii.*

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F. eumartii	*F. oxysporum*
In Stems	
Brown discoloration of vascular bundles, accompanied by necrosis of pith and cortex. Discoloration extends into upper stem and foliage. Pith often discolored at the nodes.	Discoloration chiefly confined to vascular bundles and not extending above the surface of the ground.
In Tubers	
Sunken areas at stem-end usually occur with wrinkling of tissues around margins. Internal discoloration of various types, chiefly vascular, accompanied by a soft, watery, light brown appearance of adjacent tissue about 5 to 10 mm. in diameter often extending thru the entire tuber.	Usually no stem-end rot. Internal discoloration chiefly confined to vascular bundles as a light brown discoloration.
ISOLATION	
Isolated easily from roots. Isolated with more difficulty from stems, especially in later stages of disease. Discoloration in upper stems sterile and also at the extreme ends of discolored tissue in stems and tuber. Isolated with difficulty from stored tubers.	Isolated easily from roots and stems. Often isolated as a secondary invader from stem-end rot tubers. Isolated with difficulty, but more easily than *F. eumartii*, from vascular discolorations in stored tubers.
PATHOGENICITY	

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PROGRESS OF THE DISEASE

With stem inoculations of young plants first symptoms appear in 1 to 3 weeks and complete wilt in 5-7 weeks. Slower progress with soil and seed inoculations, but complete wilt always occurring under optimum conditions.	All methods of inoculation give variable results. Often no wilting symptoms appear and diagnosis usually made on basis of vascular discoloration. Complete wilt seldom produced except at extremely high temperatures or low soil moisture.

RELATION OF SOIL TEMPERATURE TO THE DISEASE

Optimum soil temperature 20° to 25° C. Slight infection at 12°. No infection above 30°.	Optimum soil temperature above 30° C. Slight infection at 16° with heavy soil inoculation.

RELATION OF SOIL MOISTURE TO THE DISEASE

One hundred per cent infection at all moisture contents. Wilt appears first at high soil moistures, but after appearance wilt is accelerated by low soil moistures. Tuber infection greatest at high soil moistures.	Infection favored by high soil moisture. After infection, wilt is accelerated by low soil moisture.

RELATION OF INFECTED SEED PIECE TO THE DISEASE

About 50 per cent of stem-end rot seed reproduce the disease directly. Such seed produces plants more susceptible to infection from the soil than healthy seed.	A variable amount of infection occurs from infected seed. Usually only a small per cent of infection occurs in this way.

RELATION OF INFESTED SOIL TO THE DISEASE

Badly infested soil results in about 25 to 50 per cent disease even under unfavorable conditions for the disease. Infection from soil usually occurs thru the roots and may result in an internal discoloration of the healthy seed pieces by progressing down the stem.	Results from infested soil are variable, depending chiefly on environmental factors. Most of infection takes place thru the roots.

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PRODUCTION OF TOXIC EXCRETORY SUBSTANCES

Produces a toxic substance in culture capable of wilting potato tops placed in the filtrate in 30 minutes to 2 hours. Also produces a toxic substance capable of macerating potato tuber tissue in 2 to 5 hours. The activity of this substance is destroyed by boiling for 15 minutes.

Produces a toxic substance causing wilt of potato tops placed in the filtrate in 1 to 3 days. The activity of this substance is not destroyed by boiling.

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PART II

EXPERIMENTAL EVIDENCE

LABORATORY STUDIES

Source of Cultures

Single spore isolations of the first strain of *Fusarium eumartii* isolated in February, 1921, from a stem-end rot tuber from western Nebraska and listed as culture No. 64 have been used in identifying the organism and as a source of inoculum for all experiments reported in this paper unless otherwise noted. Reisolations from inoculated plants have been repeatedly obtained.

A large number of other strains of *Fusarium eumartii* have been isolated from infected plants in Nebraska and have been used for pathogenicity tests. All strains of the organism have behaved similarly. A few comparative pathogenicity tests with a culture of *F. eumartii* obtained from the United States Department of Agriculture thru the courtesy of Dr. M. Shapovalov and listed as culture No. 204 have given somewhat similar results, but Nebraska culture No. 64 produced more severe symptoms more rapidly than the Washington culture. This may have been due to the fact that the Washington culture was not in a state of "high culture." No change in the degree of virulence of culture No. 64 has been noted in 3 years.

Growth-Temperature Relations in Pure Culture

Experiment 1

Methods:—Cultures of 3 strains of *Fusarium eumartii* were grown for one week on hard potato dextrose agar[1] in Petri dishes. Disks 2 mm. in diameter were cut from these stock cultures and transferred in an inverted position to the center of a series of Petri dishes each containing 15 c. c. of a similar medium. The transfers were all made at a room temperature of 25° C. and the cultures were immediately placed at the desired temperature after inoculation.

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5.5°, 10.0°, 14.9°, 19.7°, 24.7°, 30.0°, 32.8°, and 34.5°. After an exposure of 10 days at the above temperatures all cultures were transferred to 25° to determine the effect of the previous temperatures on the subsequent growth at 25°. Measurements of the cultures were made every 24 hours by taking two readings of the diameter of the colonies and subtracting the size of the disk used in the inoculation.

Four Petri dishes were used for each of the 3 strains of *Fusarium eumartii* at each temperature. All strains behaved alike, however, and in the results presented graphically in figure 1 all cultures are grouped together.

Results:—The optimum temperature for growth was 25° C. The minimum and maximum temperatures for growth were 5° and 33°. No growth occurred at 5° until the tenth day, and no growth was observed at 33° until the third day. In this experiment no growth occurred at 35°. No tests were made at temperatures below 5°. The organism was found to be a very slow grower, producing a colony only 66.7 mm. in diameter in 10 days at the optimum temperature. The most noticeable characteristic of the results shown in figure 1 is the small amount of growth occurring at 30° as contrasted with that occurring at a temperature 5° lower.

The same type of growth-temperature curves as those shown in figure 1 will be found if the daily increments instead of the total growth are plotted. After the first 48 hours' growth, the daily increments were practically the same for successive days at each temperature and there was no apparent shifting in the optimum temperature for growth on successive days. If the temperatures employed had occurred at smaller intervals, it is possible that a shifting of the optimum temperature might have been observed, as this has been reported to occur with other organisms. With the 5° C. intervals employed here it was not observable.

The dotted lines in figure 1 represent the total growth occurring after all cultures[1] were transferred to 25° C. It was evident that the previous exposure to unfavorable temperatures influenced the rapidity of growth when the cul-

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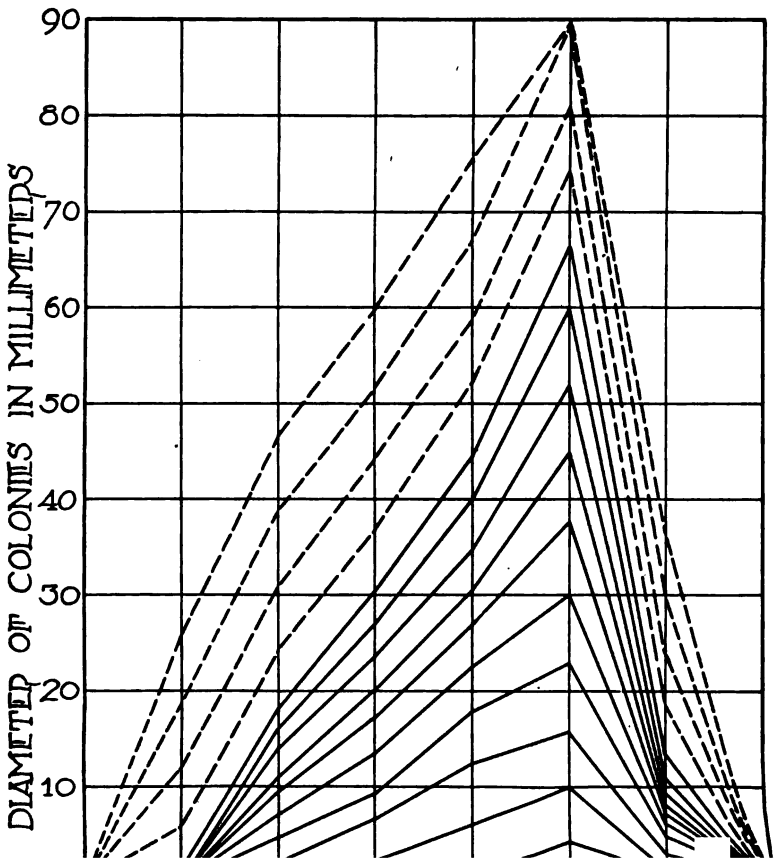

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grown at 30°, but this may have been partially due to the more rapid drying of the medium at the higher temperature.

The results presented here are in a general way in agreement with other published reports on the growth-temperature relations of this organism. Edson and Shapovalov (4) report the same optimum temperature for growth with no germination occurring at 35° C. They did not obtain growth at 5° in 7 days' exposure. In the author's experiments, growth at 5° did not occur until the tenth day. The chief difference in the results obtained by the author and those reported by Edson and Shapovalov occurred at 30°. In their experiments the growth at 30° was nearly as great as at 25°, while in this experiment less growth occurred at 30° than at 10°. The author also obtained growth at 33°, a temperature not used in their experiments. The difference in growth at 30° may be accounted for on the basis of the media used, as Edson and Shapovalov employed a 2 per cent potato agar, while in this experiment a 3 per cent potato dextrose agar was the medium employed. Later experiments (p. 32) with 2 per cent potato dextrose agar resulted in an even greater comparative growth at 30° than that reported by Edson and Shapovalov, and also considerably more growth at 33° than was found in Experiment 1, thus showing the effect of the medium employed in temperature studies of this kind.

A further test was made of the inhibiting effect of high temperatures on the growth of the organism. Cultures were made as in the preceding experiment and placed at 35° C. Each day 3 cultures were removed to a temperature of 25° and measurements made for 10 successive days. It was found that after 10 days' exposure to 35° the cultures were dry and the organism did not grow when removed to 25°. For all exposures under 10 days, the growth was retarded for the first 48 hours after which the daily increment of growth was practically the same for all cultures. The extent of this retardation increased with the length of the exposure at 35°.

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changed to 25° for 16 hours. Measurements of the increase in diameter were made every 24 hours, at the time the temperatures were changed, for a period of 10 days. The average growth for all cultures in the experiment was as follows:

Temperature		Total growth in millimeters for successive days									
35 °C	25 °C	1	2	3	4	5	6	7	8	9	10
16 hours	8 hours	0	0	0	0	0	0.1	0.9	1.7	2.3	2.7
8 hours	16 hours	2.1	6.1	8.6	11.2	13.6	17.0	20.2	23.1	25.7	28.1

Comparing the growth-temperature relations of *Fusarium eumartii* with those of *F. oxysporum* previously reported (6), grown under the same experimental conditions, it is evident that *F. eumartii* grows more slowly and that high temperatures greatly retard its growth. Whereas the optimum temperature for both organisms was about the same, 25°, *F. oxysporum* grew as well at 30° as at 25°, and with some strains this was the optimum temperature for growth; it also made a slight growth at temperatures as high as 37.5° C. The growth of *F. eumartii* was greatly inhibited at 30° and none occurred at 35° in these experiments. A greater comparative growth at the lower temperatures occurred with *F. eumartii* than with *F. oxysporum*.

Effect of the H-Ion Concentration of the Medium on Growth-Temperature Relations

Experiment 2

In this test an effort was made to determine not only the effect of the H-ion concentration of the medium on the growth of the organism, but also whether this effect would remain constant under all temperature conditions.

Methods:—Cultures were made as in the previous experiments and the following temperatures were employed: 5°, 10°, 15°, 20°, 25°, 30° and 33° C. Records taken 3 times a day during the experiment showed the following average temperatures: 4.8°, 10°, 14.7°, 20°, 24.9°, 30° and 33°. Potato dextrose agar[1] was adjusted to the following H-ion concentrations by the colorimetric method: pH 4.5—5.0—6.0—7.1—7.5 and 8.5. The experiment was run in triplicate. Measurements of the diameter of the colonies were recorded every 24 hours. The changes in the reaction of the medium due to the growth of the organism during the experiment were not determined.

Results:—As in the previous experiment, the optimum temperature for growth was found to be 25° C. At 5° growth

[1]200 grams sliced potatoes, 10 gms. dextrose, 20 gms. agar, 1000 c.c. water.

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was more rapid than in Experiment 1, being measurable in 6 days. Growth was greater at 30° and 33° than occurred in Experiment 1. The total growth for 10 days for all cultures is tabulated in Table 2 and these results are comparable with the daily total growth thruout the experiment. The great increase in growth at 30° over that occurring in Experiment 1 has already been noted on p. 30, and is probably due to the medium employed. The results here are more in accord with the data presented by Edson and Shapovalov (4) who also used 2 per cent agar.

TABLE 2.—*Effect of the H-ion concentration of the medium on the growth-temperature relations of Fusarium eumartii*

Diameter of colonies expressed in millimeters, after 10 days' growth
Experiment 2

H-ion concentration	5°C.	10°C.	15°C.	20°C.	25°C.	30°C.	33°C.
pH	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*
4.5	2.0	11.8	26.1	48.6	65.1	52.0	13.2
5.0	2.6	11.8	26.8	49.6	64.7	53.6	17.8
6.0	2.8	12.5	29.5	48.8	65.2	55.5	19.0
7.1	2.5	13.6	28.6	50.5	66.1	56.5	18.0
7.5	3.5	14.1	29.6	52.1	66.6	57.5	20.0
8.5	3.0	13.0	29.5	52.5	67.0	57.1	13.3

The reaction of the medium had very little effect on the growth of the organism; *Fusarium eumartii* is apparently able to grow well at all H-ion concentrations between a pH of 4.5 and one of 8.5. The slight difference occurring can be seen in Table 2. At the optimum temperature the reaction of the medium had no great effect on growth; if anything the more alkaline medium favored the growth of the organism. At the extreme temperatures, a greater difference was noted. The more acid medium resulted in a considerable decrease in the total growth, and this decrease was greater as the temperature departed from the optimum. The high alkaline set, pH 8.5, did not cause any great decrease in growth except at 33° C. The data presented in Table 2 are the average

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of one experiment run in triplicate, with a duplicate experiment conducted at 33° where the greatest differences occurred. From the preliminary evidence presented here, it becomes necessary to take temperature into consideration in experiments to determine the effect of H-ion concentration on the growth of an organism in culture.

The results presented here are in accordance with the available data on the natural distribution of *Fusarium eumartii*, as regards both temperature and soil reaction.

Isolation Studies

An analysis of the results of several thousand isolations made during this investigation reveals several important points regarding the behavior of the causal organism. The isolations were made from all parts of affected plants in the field and others which had been inoculated with pure cultures of *Fusarium eumartii* in the greenhouse.

Many workers have made isolation studies of potato tubers showing various types of internal discoloration. No detailed summary of these investigations need be made other than to state that the results have been variable. Usually a large number of failures to isolate any organism have been reported, the recovery of tuber-rotting species of Fusarium rather than wilt parasites has been very frequent and these were often associated with other miscellaneous fungi and bacteria. The only reported isolations of *Fusarium eumartii* are from Pennsylvania and New York. Carpenter (1) noted that the vascular bundles were often discolored in advance of the stem-end rot, and that in inoculation experiments a water-soaked zone of enzymic activity preceded the rot. Isolations from the border of such discolored bundles or from the watery zone were often negative whereas *F. eumartii* could be obtained from the margin of the discolored tissue and the watery zone. He was unable to isolate *F. eumartii* from one type of stem-end necrosis and he therefore considered this to be distinct from the disease caused by this species. Haskell (8) reported that about 60 per cent of his isolations from affected tubers yielded *F. eumartii*. No reports of the isolation of *F. eumartii* are found in any of the investigations of

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However, the following considerations may throw some light upon the investigation of diseases of this type.

During the early part of the investigation the isolations were made from tubers in the usual manner. Affected tubers were washed, treated with mercuric chloride or alcohol, cut with a sterile knife, and then broken so that a small portion of the affected tissue could be removed from the exposed surface. The isolations were always made from the extreme edge of the discolored tissue. The great majority of these isolations proved to be sterile, but often miscellaneous fungi, usually species of Fusarium and bacteria, were obtained. *Fusarium eumartii* was never obtained.

Further isolations were made from tubers, by removing a portion of tissue 6 to 12 mm. back of the extreme edge of the discolored tissue. In these cultures, *Fusarium eumartii* was recovered a number of times but the number of miscellaneous fungi present in such tissue was very great. Isolations were then made from the roots of plants which produced these tubers and these yielded *F. eumartii* in the majority of cases.

Further detailed studies were made by isolations from all parts of plants grown in inoculated soil. These isolations from the roots in nearly every instance yielded *Fusarium eumartii.* The basal stem of affected plants often revealed the causal organism, but those which were badly disintegrated also yielded a variety of fungi. Isolations from discolored pith occurring chiefly at the nodes of the upper part of the stem were always sterile. Affected tubers with the stolons still attached were removed and isolations made immediately. If the tuber was only slightly infected the organism could be recovered from the stolon, whereas many cultures from the tubers were sterile. The organism usually was recovered from tubers in which the disease was further advanced, except from the extreme edges of the discolored tissue which were always sterile. Many tissue cultures made from the extreme edges of the discolored vascular bundles on potato agar showed a deep brown discoloration of the agar after 24 hours, which increased in amount for 3 to 4 days (Plate 5, B), after which diffusion thru the agar became so general that the darkening of the medium around the tissue was not

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It was evident from these results that *Fusarium eumartii* was capable of producing a toxic substance by which the host tissue was discolored and killed for a considerable distance in advance of the organism. It was also evident that affected tubers were subject to invasion by secondary parasites which grew more rapidly than *F. eumartii* and were thus capable of overgrowing it and preventing its isolation.

These two points serve to explain why so many of our cultures from affected tubers were sterile or yielded a variety of miscellaneous fungi. It was not until these points were ascertained that a clear perspective of the problem in Nebraska was possible. An ordinary cultural study of stem-end rot tubers in storage in western Nebraska would certainly never indicate the real causal factor. However, the isolation of the causal organism from the roots and other parts of affected plants in the field and the positive results so easily obtained in infection experiments established without a doubt the identity of the real pathogene.

Toxic Secretions of the Organism IN RELATION TO WILT

The examination of sections of infected plants revealed the fact (p. 20) that the vascular elements were not blocked by the growth of the organism thus causing a wilt of the plant, but that the tissue was often killed in advance of the organism. A few preliminary tests were therefore conducted to determine whether or not *Fusarium eumartii* can produce any toxic substances which might cause infected plants to wilt.

Cultures were grown in liquid media.[1] The solution was divided into 300 c. c. portions and placed in 2-liter flasks. The cultures were grown for 3 weeks at 25° C. The fungus mat was then removed and the remaining solution filtered and treated in various ways. The tops of healthy potato plants were cut off and placed in sterile bottles containing the filtrate and placed in the shade in a greenhouse held at 18°

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Treatment	Rate of Wilting
Filtered thru cotton, boiled 15 minutes.	No wilting.
Filtered thru cotton, unboiled.	Slight wilt in 30 minutes, complete wilt in 2½ hours.
Filtered thru Mandler filter, unboiled.	Wilting in 2 to 6 hours.
Sterile culture solution.	No wilting.

It was evident from these few tests that *Fusarium eumartii* is capable of producing a toxic substance which may cause a rapid wilt of potato foliage when placed in the filtrate and which is destroyed by boiling for 15 minutes. It is possible that this toxic substance may be a factor in producing the wilt symptoms in growing plants. Wilting would also be accelerated by the destruction of roots and by the decay of the basal part of the stem. The destruction of the cortex of the roots does not necessarily result in wilt if sufficient soil moisture is available. The destruction of the host tissue may, however, give rise to decomposition products toxic to the plant, as other workers have previously pointed out. It is probable that it is a combination of these factors which causes wilting of infected plants.

The results of somewhat similar tests made by the author in 1915 with *Fusarium oxysporum* have been briefly reported (2). For purposes of comparison the methods used and the results of these tests are presented here in detail. *F. oxysporum* was grown for 3 weeks, the same length of time used in the tests with *F. eumartii*, in a similar medium. In some of these tests the mat of mycelium was removed, washed, ground up, water added, and the solution filtered thru a Berkfeld filter. In others the solution remaining after the removal of the mycelium was filtered thru a Berkfeld filter. The results were as follows:

Treatment	Rate of Wilting
Filtrate from extract of mycelium.	Slight wilt in 3 days, complete in 5 days.
Filtrate from culture.	Wilted in 24 hours.
Filtrate from culture boiled for 10 minutes.	Slight wilt in 24 hours, complete in 48 hours.
Filtrate reduced by boiling to half the initial volume.	Wilt in 12 hours, complete in 36 hours.
Spore suspension in culture medium.	Wilted in 24 hours.
Sterile culture medium.	No wilt.

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Young and Bennett (11) have reported more extensive experiments of the same general nature, with *Fusarium oxysporum*. They reported that an increase in the age of the culture resulted in a decrease in the wilting period when potato stems were placed in the filtrate. They reported a slower rate of wilting than that obtained by the author. They also reported "that autoclaving for 15 minutes or boiling for 30 minutes did not alter materially the wilting period of the filtrate."

These tests with *Fusarium eumartii* and *F. osysporum*, while not exactly comparable, differ only slightly in the methods employed and yield results that are strikingly different. The toxic action of the filtrate of cultures of *F. oxysporum* is very slow, and is not destroyed by heating; in fact, the "wilting period" is decreased when the volume of the filtrate is reduced by boiling. The filtrate from cultures of *F. eumartii* results in a rapid wilting of potato stems and the toxic action of this filtrate is destroyed by boiling.

It is significant that the comparative action of these toxic substances produced by *Fusarium eumartii* and *F. oxysporum* can be correlated with the more rapid wilting and the more destructive action of *F. eumartii* when plants are inoculated with pure cultures of the organism.

IN RELATION TO TUBER ROT

As previously noted, *Fusarium eumartii* causes a discoloration of the tissue in the potato tuber for a considerable distance in advance of the organism. A few preliminary tests were therefore made to determine whether or not the organism produced toxic substances in pure culture, capable of destroying healthy potato tissue.

The methods employed in these preliminary tests were somewhat similar to those described by Harter and Weimer (9), and the accuracy of the methods need not be discussed here. Cultures were grown for 7 days in 300 c. c. portions of potato extract at 25° C. The mycelial mat was then removed and the solution filtered thru cotton and divided into 25 c. c. portions which were placed in 125 c. c. flasks. Freshly cut potato disks 15x1.5 mm. in size were placed in the solutions, 5 in each flask, and the flasks incubated at 37.5°. The test was run in triplicate. Maceration of the disks was determined by pulling apart with the fingers.

No maceration occurred in the sterile potato extract in 24 hours. The boiled filtrate gave similar results. Unboiled

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filtrate resulted in slight maceration in 2 hours, and complete disintegration in 5 hours. In one test toluol was added to the solutions and the results were the same as those without toluol. Microscopic examination of the macerated tissue revealed the disintegration of the middle lamella and the separation of many of the individual cells.

The action of this toxic excretory substance was not as rapid as that reported for species of Rhizopus by Harter and Weimer (9). The tests reported here were small in number and of a preliminary nature, yet they give some indication of the manner in which *Fusarium eumartii* may kill the host tissue in advance of its invasion by the production of a thermolabile toxic excretion.

GREENHOUSE EXPERIMENTS

Preliminary Pathogenicity Tests

Inoculation by wounding:—Healthy Bliss Triumph plants were inoculated with *Fusarium eumartii* by introducing a small amount of spores and mycelium, with a sterile scalpel, into the stem just below the surface of the ground. Four plants were inoculated with cultures of the organism which had been grown for 2 weeks on hard oat agar.

Seven days after inoculation one plant showed the first symptoms of wilt. Five days later one stem was nearly dead and the foliage of the other stem was seriously wilted. Three days later the plant had completely wilted and was dug up. Examination showed that the organism had produced complete disorganization of the stem at the point of inoculation and had advanced several inches above the point of inoculation and also below it as far as the roots. A second plant showed symptoms of wilt 23 days after inoculation, and 5 days later the other plants developed symptoms. Two weeks later all 3 of these plants were completely wilted and when dug up revealed a similar condition to that described for the first plant.

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then planted with healthy Bliss Triumph seed. These plants did not show any marked symptoms until about 5 weeks after planting when they were growing vigorously. Two weeks later all plants showed typical symptoms of the disease as it occurs in the field. The lower leaves became slightly mottled, that is, the veins and the tissue immediately adjacent to the veins remained green while the rest of the leaf became a light greenish yellow color. Eventually all the lower leaves turned yellow and wilted; at the same time the symptoms began to appear on the younger foliage. In a little over 2 months after planting, all the plants had completely wilted and were dug. Every plant showed root injury and internal discoloration of the stem in varying amounts. Four of these plants produced tubers showing typical stem-end rot. Control plants remained healthy thruout the experiment.

Altho only a few plants were used in these tests, the results were so uniform that it was considered proof of the active pathogenic nature of the organism under consideration. The rapidity with which the organism attacked the host tissue, and the extent of invasion when direct inoculations were made into the stem, indicated a more virulent parasite than the author had previously encountered among the species of Fusarium isolated from potatoes.

In inoculated soil the disease did not progress as rapidly as from stem inoculations. However, the fact that the plants were able to form tubers before complete wilting occurred permitted observations on the new tubers. The presence of typical stem-end rot in the new tubers, in connection with the uniformity of wilt symptoms in all plants, and the similarity in the appearance of these plants to that of the disease in the field indicated that the causal organism in the production of potato wilt and stem-end rot in Nebraska had been obtained.

Infection Experiments with Controlled Soil Temperatures and Soil Moistures

Methods:—In all the following greenhouse experiments the methods used were as follows, unless otherwise noted. The soil (3 parts of soil and 2 parts of sand) was mixed in large enough quantities to provide for all experiments for one year. This soil was steamed for 4 hours at 2½ pounds pressure. Samples were then taken for the determination of the soil moisture equivalent[1]. The moisture content of the soil was determined when the containers were filled, and the moisture content was then adjusted to the desired point.

[1] The author is indebted to Mr. J. C. Russel of the Agronomy Department, Nebraska College of Agriculture, for the determination of soil moisture equivalents which are expressed in this publication by the abbreviation "M. E." with the ratio expressed by the figure prefixed; as, "1¼ M.E."

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During the experiments water was added one to three times a week, depending upon the growth of the plant. The water was added by using a small inverted clay pot placed several inches below the surface of the ground for a reservoir, the water being added thru a small glass tube. Enough of the required water was also added to the surface of the soil to keep the moisture content fairly uniform thruout the container. The surface of the soil was covered with 1000 grams of gravel to prevent baking of the surface and to reduce temperature fluctuation in the surface soil.

In the temperature experiments, galvanized iron containers were used which held 10 kilos of soil. In the moisture experiments, 3-gallon earthenware crocks holding 11 kilos of soil were used. The methods were in general similar to those previously described in experiments with *Fusarium oxysporum*, Goss (6), except that improvements were made where possible and the soil moisture contents were expressed on the basis of the moisture equivalent, which was found to be more reliable than the previous method of using the moisture holding capacity as a basis.

Soil inoculations were made by mixing with the soil, cultures of the organism grown on a mixture of rice and cornmeal. About one pint of this inoculum from 3-weeks old cultures was applied to 25 kilos of soil.

In the seed inoculation experiments the cut seed was placed for a few minutes in a spore suspension from 3-weeks old cultures on hard oat agar, and then planted immediately.

Seed pieces of approximately the same size were used thruout the experiments. The seed used for all experiments in any one year was obtained from a lot of healthy Bliss Triumphs, the only potato variety used in this study.

Two greenhouses were employed, one held at approximately 25° and the other at 18° C. Soil temperatures were maintained by the use of modified "Wisconsin soil temperature tanks." These "tanks" were kept in the 18° greenhouse. The soil temperature at a depth of 3—4 inches was recorded 3 times daily.

RELATION OF SOIL TEMPERATURE TO THE DISEASE

SOIL INOCULATION

Experiment 3, December 14, 1922—February 16, 1923

Methods:—The soil used in this experiment was kept at a moisture content of 22 per cent (dry weight) equaling the moisture equivalent. The experiment was conducted in a

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greenhouse held at a mean temperature of 18° C. Five soil temperatures were used as follows: 15°, 20°, 25°, 30°, and 35°. Records of the temperatures gave means of 14.8°, 19.7°, 24.7°, 29.8°, and 34.6°. Six inoculated plants and 2 controls were grown at each temperature.

Results:—The results of this experiment are presented briefly in Table 3. The most favorable temperature for infection and for the development of the disease was 20° C., where all inoculated plants wilted completely, (Plate 3, C). The number of plants infected and the severity of the disease decreased as the temperature departed from 20°. At 35° only 4 seed pieces in inoculated soil and one control germinated. Two inoculated and one control wilted completely owing to the extremely high soil temperature. The symptoms were the same in all 3 plants and were not typical of plants infected by *Fusarium eumartii*, which could not be recovered from these plants.

Two inoculated and one control plant grown at 18° (soil and air temperature) and changed 54 days after planting to a soil temperature of 35° with the air temperature remaining at 18° C. yielded very interesting results. The inoculated plants showed symptoms of wilt 24 hours after the change of temperature and wilted completely in 3 days, whereas the control plant, after a slight drooping and flaccidity which occurred immediately after the change of temperature, completely recovered. The quick change to such a high soil temperature undoubtedly disturbed the physiological balance of the plants. The control plant with its healthy root system was evidently able to adjust itself to the new environment. The inoculated plants, which upon digging were found to be severely infected with many of the roots destroyed, were unable to adjust themselves to the new conditions and death resulted.

The symptoms of the disease developed most rapidly at 20° C.; the first symptoms appeared in 11 days (average), and complete wilt occurred in 26 days (average) after emergence. The time increased at the higher and lower temperatures. The difference would be even more marked if the time had been calculated from the date of planting, as emergence occurred in the following order: 25°, 30°, 20°, 15°, while the disease symptoms appeared first at 20°. No differences in the rate of emergence could be noted between the control and inoculated plants. There was considerable dif-

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TABLE 3.—*Relation of soil temperature to the disease*
Soil Inoculation
Experiment 3

No. of plants	Average height	Number of plants and character of symptoms												Relative rate of progress of the disease after emergence			
		Wilt				Root infection			Internal necrosis								
									Basal stem			Upper stem					
		Healthy	Slight	Serious	Complete	Healthy	Slight	Serious	Healtxy	Slight	Serious	Healthy	Slight	Serious	Number of plants wilting	Average number of days from emergence to first symptoms	Number of plants completely wilted	Average number of days from emergence to complete wilt
	Inches																	
6	20 (25)[1]	2	3	1	0	0	4	2	0	4	2	5	1	0	4	31	0	..
6	7 (24)	0	0	0	6	0	0	6	0	0	6	0	0	6	6	11	6	26
6	12 (18)	0	0	2	4	0	0	6	0	0	6	0	1	5	6	19	4	30
6	9 (11)	3	2	1	0	0	4	2	3	1	2	6	0	0	3	31	..	..
4[2]	4 (4)	2	0	0	2	No disease appeared												
2	12 (24)	0	0	0	2	0	0	2	0	0	2	1	0	1	2[3]			

ge of control plants in parenthesis.
ontrol and two inoculated plants grown at 18° C. were placed at 35° on February 7. The tops appeared healthy at time of changing.
ns appeared on inoculated plants in 24 hours. Complete wilt in 3 days.
eed pieces did not germinate, 2 plants completely wilted due to the high temperature.

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ference in the height of the control and inoculated plants, particularly at the optimum temperature for the disease.

The relation of soil temperature to the degree of severity of root infection and internal discoloration of the stem and tops closely paralleled the appearance of the symptoms of wilt.

The control plants in all instances remained healthy except at 35°, where wilting occurred due to high temperature, and in one control at 30° C. which did not show any vascular discoloration of the stem. No causal organism could be isolated from this plant.

Twenty-four isolations were made from the roots of wilted plants grown at 15°, 20°, 25°, and 30° C. and all yielded *Fusarium eumartii.*

Experiment 4, February 17—May 18, 1923

Methods:—In this experiment the same containers and soil used in Experiment 3 were replanted with seed from the same source. No additional soil inoculation was made. The soil moisture was held at 22 per cent (dry weight), as in Experiment 3.

Soil temperatures midway between those used in Experiment 3 were employed. These were 12.5°, 17.5°, 22.5°, 27.5°, and 32° C. The containers used at these temperatures were the same ones used in the previous experiment at 15°, 20°, 25°, and 30° respectively. Those previously held at 35°, where no disease appeared, were transferred to a greenhouse kept at 25° to determine whether or not the organism had been killed or had lost its virulence. Another set of 6 containers was made up as in the previous experiment and held at 32°. Records of the soil temperatures taken 3 times daily averaged as follows: 12.6°, 17.9°, 22.4°, 26.7°, and 31.6°. At the two highest temperatures the average was slightly below the desired point.

The experiment was conducted in a greenhouse held at a temperature of 18° C. Notes were taken thruout the experiment as in Experiment 3, and in addition, data were collected on the infection of the new tubers.

Results:—The results of this experiment are presented in Table 4. The most favorable temperature for the development of the disease was 22.5° C. where all inoculated plants were infected and 5 out of 6 completely wilted. The injury to all parts of the plant including the amount of infection in the new tubers was greatest at this temperature. At temperatures below the optimum, infection occurred in all plants but the disease was not as severe. Above the optimum both

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TABLE 4.—*Relation of soil temperature to the disease*
Soil Inoculation
Experiment 4

Soil temperature	No. of plants	Average height	Number of plants and character of symptoms												Effect of disease on tuber production					
			Wilt				Root infection			Internal necrosis: Basal stem			Internal necrosis: Upper stem			Number of plants producing tubers		Average weight of tubers per plant		Per cent of tubers infected (by weight)	
			Healthy	Slight	Serious	Complete	Healthy	Slight	Serious	Healthy	Slight	Serious	Healthy	Slight	Serious	Control	Inoculated	Control	Inoculated	Control	Inoculated
°C.		*Inches*																*Grams*		*Per cent*	
12.5	6	32 (37)[4]	3	3	0	0	0	5	1	4	2	0	6	0	0	1	2	43	35	0	0
17.5	6	15 (24)	2	1	0	3	0	3	3	0	3	3	4	0	2	2	4	125	77	0	37
22.5	6	13 (22)	0	1	0	5	0	1	5	0	1	5	2	3	1	2	6	130	107	0	44
27.5	6	21 (18)	1	0	3	2	1	2	3	1	2	3	6	0	0	2	4	70	69	0	18
32	2	12 (17)	0	1	0	1	1	0	1[2]	1	0	1	1	0	1	..	..	..	..	..	..
18—32[1]	2	20 (26)	0	0	2	0	0	0	2	0	0	2	0	2	0	..	..	..	..	..	..
25[3]	6	19 (21)	0	0	4	2	0	2	4	0	2	4	6	0	0	2	4	60	39	0	90

[1]Two plants previously grown at 18° were changed to 32° C. on April 3.
[2]Isolations from roots of this plant did not yield *Fusarium sumarili*.
[3]Soil and air temperature both 25°.
[4]Average height of control plants in parenthesis.

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the amount of infection and the severity of the disease decreased. At the maximum temperature used, 32°, four of the seed pieces failed to germinate. Both plants which developed wilted, altho one was probably due to high temperature, as no trace of infection could be found in the underground portions. Plants started at 18° and changed to 32° showed rather rapid wilting immediately after placing them at the higher temperature. The action here was probably similar to that noted in Experiment 3. In the greenhouse held at 25°, the disease occurred in all inoculated plants and progressed in about the same way as at 22.5°. This soil had been held at 35° during the previous experiment and no disease occurred. It is evident, therefore, that the organism was not killed at that temperature.

Many of the severely infected plants in this experiment failed to produce tubers. The average weight of tubers from inoculated plants was considerably less than from the controls. A high percentage of the progeny of inoculated plants showed typical stem-end rot as illustrated in Plate 1, B, C. The per cent of stem-end rot would be higher if the number of tubers rather than the weight had been used for comparison, as most of the infected tubers were smaller.

Inasmuch as the seed used in this experiment had been in storage longer than that used in Experiment 3, the germination and the early growth of the plants was more rapid. As a result the first symptoms did not appear as early as in the previous experiment, and the disease did not progress as rapidly in the infected plants. Considerable variation in the time of appearance of symptoms occurred in different plants held at the same temperature. This was apparently due to the fact that if infection occurred early or if a plant grew slowly at any temperature above 17.5° C. it wilted much more quickly than one that had managed to develop a good root system before the disease had progressed very far.

The controls in all cases remained healthy except at 32° C. where slight wilting occurred altho the causal organism could not be recovered in culture. Wilting in this case was probably due to the high soil temperature.

SEED INOCULATION

Experiment 5, November 8, 1923—February 11, 1924

Methods:—The soil used in this experiment was steamed in the same way as in previous experiments. The soil moisture equivalent was 15 per cent dry weight. Inasmuch as the soil

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TABLE 5.—*Relation of soil temperature to the disease*
Seed Inoculation
Experiment 5

Soil temperature	Number of plants	Average height	Number of plants and character of symptoms																		Relative rate of progress of the disease after emergence			
			Wilt				Root infection[1]			Internal necrosis							Seed piece infection				Resulting tubers							
										Basal stem				Upper stem														
			Healthy	Slight	Serious	Complete	Healthy	Slight	Serious	Healthy	Slight	Medium	Complete	Healthy	Slight	Serious	Healthy	Slight	Serious	Complete	Number healthy	Number infected	Number of plants wilting	Average number of days from emergence to first symptoms	Number of plants completely wilted	Average number of days from emergence to complete wilt
°C.		*Inches*																								
12	6	21	6	0	0	0	6	0	0	5	1	0	0	6	0	0	1	3	2	0	19	0	0	..	0	..
16	6	21	1	4	1	0	3	2	1	1	1	2	2	3	1	2	0	1	0	5	10	5	5	25	0	..
20	6	6	0	0	1	5	0	0	6	0	0	5	1	0	0	6	0	0	0	6	0	2	6	19	5	33
24	6	8	0	0	2	4	0	0	6	0	0	2	4	0	1	5	0	0	0	6	0	2	6	12	4	20
28	6	6	0	0	1	5	0	0	6	0	0	0	6	0	0	6	0	0	0	6	0	3	6	18	5	53
32	6		Infected plants and controls appeared the same, complete wilt due to high temperature																							

[1]Root infection at all temperatures started at the base of roots adjoining the infected stems.

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contained more sand than that used in previous experiments, the moisture content was kept at 18 per cent (dry weight). Six different soil temperatures were used, 12°, 16°, 20°, 24°, 28°, and 32° C. The air temperature was kept at 15° to 18°. Records of the soil temperatures showed averages of, 11.9°, 15.9°, 23.9°, 27.4°, and 31.3°.

Healthy Bliss Triumph tubers were inoculated by dipping the freshly cut seed in a spore suspension of *Fusarium eumartii*. They were planted immediately and placed at the desired temperature. Six inoculated and 2 control plants were grown at each temperature.

Results:—The notes taken thruout the experiment and the data collected when the plants were dug are presented in Table 5. The relation of soil temperature to infection from the seed is approximately the same as in the previous experiments with soil inoculation. The disease was most severe at temperatures of 20° to 28° C. The wilt symptoms were most rapid at 24°. Slight infection of the basal portion of the stem occurred in one plant at 12°, and the number and severity of stem infections increased with increasing temperature. Discoloration of the pith of the upper stem also occurred more severely at the higher temperatures. Both inoculated and control seed pieces had all rotted at the close of the experiment except at 12°. The plants at 12° and 16° were still growing vigorously at the end of the experiment and the symptoms of the infected plants would probably have been more severe if they had been dug later. Tuber infection occurred at 20°, 24°, and 28°, but the number of tubers was small owing to the early death of the plants.

At 32° all the plants, including the controls, completely wilted, the foliage was chlorotic, severely spotted, and both the leaves and stems were badly streaked; the pith of the stem was disorganized and the basal part of the stem considerably rotted. It was impossible to distinguish between infection and the effects of the high temperature, so no detailed notes are given for this temperature.

The control plants at all other temperatures remained healthy thruout the experiment.

RELATION OF SOIL MOISTURE TO THE DISEASE
SOIL INOCULATION

Experiment 6, December 14, 1922—January 26, 1923

Methods:—This experiment was conducted in a greenhouse having a mean temperature of 23.4°, with a mean maximum of 24.8° and a mean minimum of 23.1° C.

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In this experiment 52 three-gallon crocks were used. The methods employed have been described on p. 39. The soil was inoculated in the same way and at the same time as in Experiment 3.

The moisture equivalent of the soil was 21.9 per cent. The experiment comprised 3 sets as follows: One set of 4 controls and 9 inoculated plants, held at 22—20 per cent (dry weight), this being approximately equal to the moisture equivalent; one set of 8 controls and 18 inoculated plants was kept at 27 per cent, or 1¼ M. E.; and one set of 4 controls and 9 inoculated plants was kept at 33 per cent or 1½ M. E.

Results:—The first symptoms of disease appeared 27 days after planting and 9 days after emergence. The next day 16 plants showed symptoms of the disease. The disease at this time progressed very rapidly, the lower leaves wilting and dying within 48 hours after the first symptoms appeared. The first appearance of the disease in this experiment was characterized by the following symptoms noted on a typical plant: ten days after emergence the lower leaf appeared flaccid and after 24 hours showed a yellowing or drying at the basal margins; the petiole turned brown, shrivelled, and hung to the stem by a thread. By this time the leaves higher up began to show the same symptoms. On the third day, the entire tops of infected plants were flaccid and drooping. At this time, chlorotic leaves showed black veins when held against the light, the petiole showed a black vascular system, and if the main stem was held against a strong light a brown flecking was apparent in the pith.

Occasionally leaves with incipient mottling and yellowing appeared similar to affected plants under field conditions but in general the disease progressed more rapidly than usually occurs in the field.

The results of this experiment are presented in Table 6. No effect of the disease could be noted on germination. When the plants were dug on January 26, only 43 days after planting, 100 per cent infection was evident. Only one plant out of the 32 plants grown on inoculated soil failed to show wilt symptoms, and 23 plants had already completely wilted.

The greatest percentage of plants with complete or severe wilt occurred in the set with the highest moisture content. All these plants would undoubtedly have wilted completely if the experiment had been allowed to continue, but the difference between the various sets would not have been as marked. The effect of the higher moisture content was shown in the degree of injury, the disease appearing earliest, the

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TABLE 6.—*Relation of soil moisture to the disease*
Soil Inoculation

Experiment 6

Soil moisture[1]	Number of plants	Average height	Number of plants and character of symptoms																Relative rate of progress of the disease after emergence			
			Wilt				Root infection			Internal necrosis: Basal stem			Internal necrosis: Upper stem			Seed piece infection				Number of plants wilting	Average number of days from emergence to first symptoms	Number of plants completely wilted	Average number of days from emergence to complete wilt
			Healthy	Slight	Serious	Complete	Healthy	Slight	Serious	Healthy	Slight	Serious	Healthy	Slight	Serious	Healthy	Slight	Serious	Complete				
		Inches																				
1 M. E.	8	6 (9)[2]	1	1	2	4	0	2	6	0	4	4	1	2	5	0	2	4	2	7	10	4	17
1¼ M. E.	15	10 (20)	0	1	3	11	0	1	14	0	3	12	1	1	13	0	3	8	4	15	8	11	19
1½ M. E.	9	12 (21)	0	0	1	8	0	0	9	0	0	9	0	0	9	0	2	5	2	9	10	8	22

[1]Soil moisture content is expressed as proportion of the moisture equivalent.
[2]Average height of healthy control plants in parenthesis.

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progress of the disease being slower but eventually resulting in more complete penetration of all host tissues affected.

An examination of the figures in Table 6 relative to the amount of root infection and seed infection shows very clearly how infection occurred. Out of 36 plants only 8 showed complete rotting of the seed piece, 4 being bacterial rots which prevented germination. Twenty-three out of 32 seed pieces grown in inoculated soil showed healthy tissue around the sprout, and 19 showed vascular discoloration in the seed tubers originating at the base of the stem. There is no positive proof that this infection of the vascular system in the seed piece started in the roots and progressed thru the stem to the seed. However, 8 of the wilted plants showed healthy tissue surrounding the sprout whereas the root systems of all wilted plants were seriously infected, thus indicating strongly that infection occurred almost entirely thru the roots. It was also clear that all seed pieces became infected from the soil, but the rapidity of the action of the root infection caused death of the plant before the seed piece infection could reach the stem, (Plate 7, A).

Practically all of the inoculated plants were dead before tuber formation occurred. All control plants remained healthy thruout the experiment.

Experiment 7, February 5—May 25, 1923

This experiment was planned to obtain data on the effect of both temperature and soil moisture on the development of the disease.

Methods:—The containers and the same soil used in the previous experiment were replanted with tubers from the same source. The soil moisture content, therefore, was at the desired point before planting, with the exception of the set at the lowest moisture content which was allowed to dry out to the desired point before beginning the experiment. Soil

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TABLE 7.—*Relation of temperature and soil moisture to the disease*
Soil Inoculation
Experiment 7

ıperature	Number of plants	Average height	Number of plants and character of symptoms												Relative rate of progress of the disease after emergence	
			Wilt				Root infection			Internal necrosis						
										Basal stem			Upper stem			Number of plants wilting	Average number of days from emergence to first symptoms
			Healthy	Slight	Serious	Complete	Healthy	Slight	Serious	Healthy	Slight	Serious	Healthy	Slight	Serious		
°C.		*Inches*															
19	4	23 (26)[2]	2	1	1	0	0	3	1	0	2	2	3	0	1	2	44
23.5	3	15-1[3] (22)	0	0	1	2	0	1	2	0	1	2	1	0	2	1	32
19	4	19 (25)	2	2	0	0	0	3	1	3	1	0	4	0	0	2	78
23.5	5	17 (28)	1	0	0	4	1	2	2	1	2	2	5	0	0	5	35
19	4	24 (21)	0	4	0	0	0	1	3	0	3	1	4	0	0	5	58
23.5	5	28 (36)	0	1	2	2	0	3	2	1	2	2	4	1	0	5	48
19	4	24 (24)	1	3	0	0	0	3	1	1	2	1	3	1	0	3	72
23.5	5	39 (38)	0	1	3	1	0	2	3	0	2	3	3	2	0	5	35

·e content is expressed as proportion of the moisture equivalent.
ght of healthy controls in parenthesis.
were infected from the seed piece which had rotted when the sprouts were 1 inch high. The entire sprout and roots were killed.
ces in this set failed to sprout.

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Results:—The results of this experiment presented in Table 7 showed much the same relation to Experiment 6 as all the other experiments conducted at this time showed to the other tests run earlier in the year. The older seed, combined with better sunlight conditions, appeared to favor the growth of the host plant and to delay the appearance of disease symptoms. During the latter part of the experiment, the air temperatures in both houses were considerably above the desired points.

The first plants to appear above ground were at the higher soil moisture contents and they were considerably earlier at the higher temperature. The earliest appearance of the disease was at 23° C. in the set with the highest moisture content. After the first appearance of the disease, the wilt progressed most rapidly in the set with the soil moisture equal to the moisture equivalent. The amount of root and stem injury, however, was greater at the higher soil moisture contents, but the large amount of available water prevented rapid wilting of these plants.

At 19° C. the disease first appeared in the set with a moisture content of 1¼ M. E. The greatest amount of disease occurred in this set as judged by both the above and below-ground symptoms, and also by the number of infected new tubers. With a moisture content of 1½ M.E. the resulting tubers showed more extensive stem-end rotting than at the lower moisture contents. The relative rate of progress of the disease at this temperature was difficult to determine, owing to the late appearance of the symptoms. In general, the plants were much healthier and more vigorous at this than at the higher temperature.

All control plants in this experiment remained healthy. *Fusarium eumartii* was repeatedly isolated from infected roots of diseased plants.

SEED INOCULATION

Experiment 8, December 14, 1922—February 14, 1923

Methods:—In this experiment steamed, uninoculated soil was used. Freshly cut seed pieces from the same source as used in the previous experiments were dipped in a water suspension of spores of *Fusarium eumartii* just before planting. The experiment comprised 4 sets, each having 7 inoculated and 2 control plants. The same 4 soil moisture contents were used as in the previous experiment, being 2/3, 1, 1¼, and 1½

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TABLE 8.—*Relation of soil moisture to the disease Seed Inoculation*

Experiment 8

Number of plants	Average height	Number of plants and character of symptoms															Relative rate of progress of the disease after emergence		
		Wilt				Root[2] infection			Rot of basal stem[3]			Internal necrosis							
												Basal stem			Upper stem				
		Healthy	Slight	Serious	Complete	Healthy	Slight	Serious	Healthy	Slight	Serious	Healthy	Slight	Serious	Healthy	Slight	Serious	Average number of days from emergence to first symptoms	Number of plants completely wilted	Average number of days from emergence to complete wilt
	Inches																		
7	10 (5)[4]	0	0	2	5	0	3	4	0	4	3	0	3	4	5	1	1	19	5	33
7	12 (18)	0	1	2	4	0	4	3	0	3	4	0	1	6	4	0	3	19	4	60
7	21 (22)	0	2	4	1	0	5	2	0	4	3	0	3	4	4	3	0	21	1	40
7	25 (26)	0	2	4	1	0	3	4	0	4	3	0	2	5	2	2	3	23	1	41

[1] Moisture content is expressed as proportion of the moisture equivalent.
[2] Root injury was confined to the first roots originating at the base of the stem, and infection progressed from the base towards the tip of the root. No root injury occurred on roots originating above the stem injury.
[3] Inoculated seed pieces were completely rotted; all control seed pieces remained healthy.
[4] Average height of healthy controls in parenthesis.

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M. E. The moisture equivalent was 21.9 per cent (dry weight).

The set at the lowest soil moisture content, however, differed from previous experiments in that the experiment was started with a water content equal to the moisture equivalent and allowed to dry out during growth to a moisture content of 2/3 M. E. The experiment was conducted in the same greenhouse as the previous experiment which had a mean temperature of 23.6° C.

Results:—The results are shown in Table 8. The disease progressed much more slowly in this experiment than in the experiment with inoculated soil which was conducted at the same time (compare Table 6 with 8). The slow advance of the disease resulted in foliage symptoms similar to the aspect of the disease in the field. The first symptoms did not appear until about 20 days after emergence as compared with about 10 days for soil inoculations in Experiment 6. A greater number of plants completely wilted in the set started at 1 M. E. and allowed to dry out to 2/3 M. E., thus showing that after infection occurred at a favorable soil moisture, the wilting symptoms were accelerated by a drop in the soil moisture content. One hundred per cent germination and infection were obtained in this experiment.

Examination of each plant at digging time showed that the seed pieces were all rotted and that the disease had progressed up the stem (Plate 7, B). The actual amount of rotting of the stem did not vary greatly at the different soil moisture contents. It was found that all roots above the infected area of the stem were healthy whereas those at the base of the main stem were all infected, the infection progressing from the base of the root out towards the tip, the exact reverse of the method of infection in the soil inoculation experiments.

With the higher soil moisture contents, the larger root systems were able to counteract the effects of the disease and keep the tops alive for a considerable length of time altho the infection in the stem was often as great as at the lower moisture contents at which the plants wilted more quickly.

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was allowed to dry out to 2/3 M. E. before planting, and the various sets were brought up to the desired moisture content just previous to planting. The methods used were the same as in the previous experiment, and the seed used was from the same source.

Forty-eight plants were used in this experiment and they were divided into 2 sets, one set being kept in a house held at a mean temperature of 23.6° and the other in a house held at 18.3° C. During the last two weeks of the experiment the temperature during the middle of the day was considerably above the average point desired.

At each temperature the experiment was divided into 4 sets held at moisture contents of 2/3, 1, 1¼, and 1½ M. E. Four inoculated plants and one control were grown at each moisture content and at each temperature.

Results:—The results of this experiment are presented briefly in Table 9. The progress of the disease was much slower than in the previous experiment, conducted in the same manner, as has been noted for other experiments conducted at the same time. The slower progress of the disease resulted in the development of symptoms very similar to the average symptoms found under field conditions. The first symptoms at the higher temperature appeared in the set held at 1½ M. E.; however, complete wilt occurred latest at this moisture content. The most rapid wilting occurred at the low moisture contents. At 18° C. the appearance and development of the disease were much slower. The first symptoms appeared at a moisture content of 1 M. E. altho in this set no complete wilting occurred.

As regards the resulting tubers, the greatest infection occurred at the low moisture contents where very small tubers were produced. At the high moisture contents the yields were greater and fewer tubers were infected. The controls gave 2 to 5 times as large yields as inoculated plants at each moisture content.

One hundred per cent infection was obtained at all moisture contents and at each temperature, the controls remaining healthy in every instance. The amount of infection and the development of the disease in the different sets were approximately the same as in previous experiments.

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TABLE 9.—*Relation of soil moisture to the disease*
Seed Inoculation
Experiment 9

Temperature	Soil moisture[1]	Number of plants	Average height	Number of plants and character of symptoms														Relative rate of progress of the disease after emergence			
				Wilt				Root[2] infection			Rot of basal stem			Internal necrosis								
														Basal stem			Upper stem						
				Healthy	Slight	Serious	Complete	Healthy	Slight	Serious	Healthy	Slight	Serious	Healthy	Slight	Serious	Healthy	Slight	Serious	Number of plants wilting	Average number of days from emergence to first symptoms	Number of plants completely wilted	Average number of days from emergence to complete wilt
°C.			*Inches*																				
23.6	2/3 M. E.	4	3 (24)[4]	0	0	1	3	1	0	3	0	0	4	0	0	4	0	0	4	4	14	3	19
	1 M. E.	4	12 (26)	0	0	1	3	0	1	3	1	2	1	0	0	4	0	0	4	4	15	3	39
	1¼ M. E.	5	16 (28)	0	0	1	4	1	2	2	0	2	3	0	0	5	1	1	3	5	13	3	59
	1½ M. E.	5	19 (30)	0	0	3	2	0	1	4	0	3	2	0	0	5	2	3	0	5	17	2 (1)[3]	35 (15)
18.3	2/3 M. E.	5	6 (14)	0	0	2	3	0	3	2	0	2	3	0	0	5	1	3	1	5	29	3	55
	1 M. E.	5	11 (24)	0	3	2	0	0	3	2	0	0	5	0	0	5	0	1	4	5	18	0	..
	1¼ M. E.	5	17 (24)	0	0	2	3	1	2	2	0	1	4	0	0	5	2	2	1	5	33	3	79
	1½ M. E.	5	19 (24)	0	0	2	3	0	2	3	1	0	4	0	2	3	4	1	0	5	36	3	84

[1]Soil moisture content is expressed as proportion of the moisture equivalent.
[2]In all cases root infection had proceeded from the stem, the primary infection coming from the seed piece.
[3]Infection took place at eye instead of thru cut surface of seed.
[4]Average height of healthy controls in parenthesis.
NOTE—In several cases the infected plants died when 3—6 inches high and it was found that infection had taken place in the tissue around the sprout, rather than thru the cut surface of the seed tuber.

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Thansmission of the Disease by Stem-End-Rot Seed Tubers

Experiment 10, March 8—May 15, 1922

During the winter of 1921-22, a number of potatoes were secured from western Nebraska showing varying degrees of stem-end rot and various forms of dry rot. A sample consisting of 42 tubers was selected to determine whether or not the disease could be transmitted by such seed.

Methods:—From half of each of the 42 tubers, isolations were made in the usual way. The other half of each tuber was planted in a greenhouse kept at about 25° C. A number of seed pieces were at least half rotted.

Results—Isolation Studies:—All the tubers examined showed a sunken diseased area at the stem-end. The internal appearance varied somewhat, and the tubers were classified in different groups. These groups with the results of the isolations are shown in Table 10. Cultures were made from the extreme ends of the discolored vascular system, or from the edge of the rotted tissue. A large number of the cultures were sterile; many yielded miscellaneous species of Fusarium. Only 4 tubers revealed the presence of *Fusarium eumartii* and 3 yielded *F. oxysporum*. No correlation could be made between the species isolated and the type of injury occurring in the tubers. The most noteworthy feature was the large number of sterile cultures. These cultures were made from the extreme end of the rotted tissue, and later experiments have shown that such tissue is usually sterile when the disease has been produced by *F. eumartii* as discussed on p. 33.

Greenhouse tests:—No typical wilting was observed in any of the plants grown from these badly rotted tubers. The plants in this test were dug at the end of about 9 weeks, and it may have been that wilting would have occurred had it been possible to continue the experiment. The results are shown in Table 10. Plants listed as diseased are those in which rotting or vascular discoloration of the stem occurred. While the number of plants was very small, it can be noted that 3 out of 4 plants yielding *Fusarium eumartii* were diseased and that none of the 3 plants yielding *F. oxysporum* showed evidences of infection. The number of diseased plants was small from those seed tubers yielding no organism in culture. As in the cultural studies the variation in results and the small number of tubers prevent any clear-cut distinctions between the type of injury in the seed and the resulting disease.

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TABLE 10.—*Transmission of the disease by stem-end-rot seed tubers*

Experiment 10

Type of seed piece injury	Organisms isolated from seed pieces											
	Sterile		*F. eumartii*		*F. oxy.*		*F. sp.*		Misc.		Total	
	Resulting plants											
	Healthy	Diseased	Healthy	Diseased	Healthy	Diseased	Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
1. Stem-end rot with vascular discoloration												
a. with rotting of adjacent tissue	8	0	0	1			4	1	3	0	15	2
b. with no rotting of adjacent tissue	3	3					2	2	2	0	7	5
c. with black necrotic strands not confined to vascular system	2	0	1	0	2	0	1	1			6	1
2. Severe stem-end rot with no vascular discoloration	1	1	0	2	1	0	1	0			3	3
Total	14	4	1	3	3	0	8	4	5	0	31	11

Experiment 11, November 14, 1923—February 14, 1924

During the winter of 1923-1924, a number of tubers obtained from the 1923 field experiments (Exp. 14 and 15) were grown in the greenhouse to study the effect of stem-end rot seed on the occurrence of the disease. The type of infection was determined for each tuber, they were then planted in soil which had been steamed for 4 hours at 2 pounds pressure, and were grown in 8-inch clay pots in a greenhouse maintained at a temperature of about 25° C.

The results are presented in Table 11. No correlation could be made between the types of stem-end rot and vascular discoloration in the seed piece and the resulting disease. Three seed pieces failed to sprout. Only about one-half of the plants grown from infected or rotted seed pieces showed any symptoms of disease. Only one plant wilted completely

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and more plants were infected at the base of the stem than were indicated by the above-ground symptoms. About 20 per cent of the tubers produced showed evidences of stem-end rot. *Fusarium eumartii* was isolated from a number of the infected stems and tubers. The control plants remained healthy thruout the experiment.

TABLE 11.—*Transmission of the disease by stem-end-rot seed*

Experiment 11

Number of seed	Number germinated	Number of plants with wilt				No. of plants with infection of basal stem				Number of infected tubers	Number of healthy tubers	Number of plants barren
		Healthy	Slight	Serious	Complete	Healthy	Slight	Medium	Severe			
Stem-end rot 60	57	38	11	7	1	29	9	3	16	19	71	9
Controls 15	15	15	0	0	0	15	0	0	0	0	37	9

The majority of the seed pieces planted in this experiment were rather severely infected, most of them being the same type as that shown in Plate 1, D. The resulting disease was not as great nor as severe as would usually be expected from seed of this type. Evidently the primary parasite was either absent or overgrown by secondary invaders in many of the seed tubers showing stem-end rot.

Method and Effects of Infection from the Soil

Method of infection:—While previous experiments have clearly shown that infection can take place from the soil thru the roots, the following test was conducted in such a way that it was possible to observe the progress of this type of infection.

Large glass cylinders were half filled with sterilized sand

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cylinder. The lower part of the cylinder was covered with black paper except when observations were made. Three weeks after planting, the tips of many of the smaller roots were observed to be infected. This appeared as a progressive browning of the part infected, and the killing of all the root hairs. Ten days later the tops of the plants were wilted and the vascular system and pith were discolored for a considerable distance into the tops. When dug, the root system of each plant was found to be seriously infected, and many of the small roots were entirely destroyed. Plate 5, A, shows the appearance of the roots by means of a photograph taken thru the glass wall of the cylinder during the latter part of the experiment. *F. eumartii* was recovered from these roots.

Effect of root infection from the soil:—In many of the experiments reported with soil inoculations it was found that while the seed piece of wilted plants was only slightly rotted from the cut surface, there was very often a discoloration of the vascular system from the sprout back into the seed piece, sometimes reaching the rotted surface (Plate 7, A), and sometimes apparently separated from it by healthy tissue.

In order to determine whether this development of vascular discoloration of seed pieces after planting was the result of infection thru the seed piece or the roots, the following tests were made:

Healthy Bliss Triumph seed was sprouted in sterile sand. When the sprouts were 2 inches high and a good root system had developed, the sand was carefully washed off and they were planted in inoculated soil. The seed piece, however, was not allowed to come in contact with the soil but was separated by placing it in a small clay pot, with the sprout and roots projecting thru the small opening and fixed in place with grafting wax. Sixteen days after planting, all the plants showed symptoms of wilt and 5 days later were completely dead. When dug the roots were found to be almost entirely destroyed and the seed piece had remained sound. There was present, however, a vascular discoloration extending from the roots up the stem into the tops and down the stem into the seed piece.

Further tests were made as follows: Healthy seed pieces were sprouted in sterile sand. When the roots were 3 to 4 inches long, the seed pieces were transplanted into sterile soil in 12-inch pots, which were divided by a board running from the bottom of the pot to about 1 inch above the surface of the soil. A close fit with the sides of the pot was obtained,

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and in this way the soil on each side of the board was kept separate. A small hole was cut thru the board several inches below the surface of the soil. The seed piece was planted close to this hole and 2 or 3 of the small roots were drawn thru the hole into the other half of the pot. In various tests these roots were inoculated either by placing a small portion of an agar culture of *Fusarium eumartii* directly on the roots, by inoculating the soil around these roots, or by placing the roots in a test tube containing a spore suspension of the organism. After inoculation of the roots, the soil was placed over them so that growth could continue.

The results were practically the same with each method of inoculation. The inoculated roots became infected, the organism probably reached the stem and the effects of its presence were evidenced by necrosis and discoloration of the tissues not only in an upward direction but also downward to the base of the stem, resulting in a browning of the vascular tissue in the otherwise healthy seed piece. Plate 6, A, shows an example of one of these plants in which wilting of the leaves is apparent. Infection of the roots and seed piece is shown in Plate 6, B. Undoubtedly the observation in the field of such a seed piece would lead one to the erroneous conclusion that infection had occurred thru the seed piece.

These tests showed that a small amount of inoculum applied to only a few roots was capable of producing the typical disease. It was also shown conclusively that it is possible to produce a vascular discoloration in a healthy seed piece as a result of root infection, thus pointing out the unreliability of casual observations made in the field to determine the method of infection.

Discussion of Greenhouse Experiments

Preliminary pathogenicity tests with *Fusarium eumartii* showed it to be a very virulent parasite causing a wilt of the plant and a stem-end rot of the tuber. Infection was obtained by both soil and seed inoculations.

The relation of soil temperature to the disease was determined under controlled conditions. Both soil and seed inoculations resulted in the appearance of the disease; the greatest amount and severity occurred at soil temperatures between 20° and 25° C. At temperatures above and below this optimum range, the number of infections and the severity of the symptoms decreased. A slight amount of infection occurred at a temperature as low as 12°. The root injury at

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the low temperatures was greater than was indicated by the wilt symptoms. Considerable infection occurred as high as 30° but infection could not be determined above 30°. At 32° and 35° sprouting was poor, growth was abnormal, and wilting and sometimes vascular discoloration and root injury occurred due to the high soil temperatures. Plants which were infected at a low temperature wilted very rapidly when transferred to soil temperatures above 30°. The infection of the new tubers did not indicate the real damage caused by this disease, as most of the seriously infected plants failed to produce tubers.

The relation of soil moisture to the disease was also determined under controlled conditions and showed the same relative results for both soil and seed inoculations. The disease progressed more rapidly, however, with soil inoculations.

The disease always appeared earliest with the high moisture contents where the wilt symptoms advanced slowly but the disease eventually resulted in more complete penetration of all host tissues affected, including the new tubers. After the first appearance of the disease, wilt progressed most rapidly at the lowest moisture content. Apparently at high moisture contents rapid wilting of the plant is prevented by the abundance of soil moisture, even when the roots are badly decayed, (Plate 4). Usually at these high moisture contents the disease progresses so slowly that new tubers are usually formed which in every instance show stem-end rot. After infection occurred at high moisture contents a sudden drop in the moisture content accelerated the wilt.

The relation of soil moisture to the disease was the same at a temperature of 18° as at 25° C. The disease always appeared first, however, at a higher temperature.

In all the soil moisture experiments 100 per cent infection was obtained. The host relation to the environmental conditions apparently determined the progress of the disease in all these tests. This was not entirely true, however, in the soil temperature experiments, where the progress of the disease was greatly affected by the growth-temperature relations of the pathogene. This was shown by the severity of the disease at the optimum temperature for the growth of the organism, and also by the maximum and minimum temperatures for the disease which closely approximate those for the pathogene.

A detailed examination of all plants, including the seed pieces, in both the moisture and temperature experiments showed that soil inoculation resulted almost entirely in root

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infection. Inoculation of seed pieces caused them to rot, and resulted in the progression of the disease up the stem and sometimes out into the roots. In such cases, however, the base of the roots was always heavily infected, while with soil inoculations the tips of the roots were the first to show infection.

In all these experiments it was found that when seed had been stored for some time before planting, sprouting was more rapid, the plant made a better start, and the first disease symptoms appeared considerably later than when the seed had not fully completed its rest period. As a result, seed stored the longest gave disease symptoms very similar to those appearing in the field.

Experiments with stem-end rot seed showed that the type of injury in the seed piece could not be correlated with the kind of organism isolated nor with the disease which developed in the plant. Wilt symptoms in all cases were very slight. About 50 per cent of the plants grown from such stem-end rot tubers remained healthy thruout the experiment. It was apparent, however, that the disease could be transmitted in this manner.

Tests were made to determine more accurately the manner of infection from inoculated soil. It was found that infection could take place thru the roots and that as a result of such root infection the seed piece could become infected by the downward progress of the disease in the stem. It is thus evident that casual examination of the seed piece in the field is not always a good method of determining the manner of infection, as one or two root infections are sufficient to produce symptoms of the disease in both the plant and the seed piece.

When the results of these experiments are compared with those of similar tests previously reported (6) with *Fusarium oxysporum*, it is at once evident that *F. eumartii* is the more virulent parasite and that the experimental results are more

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FIELD EXPERIMENTS

Seed Inoculation

Experiment 12, 1921

In this experiment inoculated seed was planted at 3 different locations in Nebraska to determine the effect of environment on the disease under field conditions.

Methods:—Healthy Bliss Triumphs were used for both inoculated and control rows. Inoculations were made by 3 different methods to determine the effect of such methods of infection. Spore suspensions in water from 14-day-old cultures of *Fusarium eumartii* were used for the inoculum. The first method of inoculation consisted in boring a hole in the seed tuber 1 to 1.5 cm. deep and 3 mm. in diameter, in which were placed small glass tubes containing 0.5 c.c. of the spore suspension. In the second method the tubers were inoculated by immersing the freshly cut seed pieces in a spore suspension just before planting. The third method was similar except that the seed pieces were allowed to callus over for 3 days before inoculating. The 3 different experimental plots used and their locations were as follows:

Plot 1—Agricultural College, Lincoln, Nebraska.
Plot 2—Substation, Mitchell, Nebraska, dry land culture.
Plot 3—Substation, Mitchell, Nebraska, irrigated culture.

Plot 1 was planted April 20 and dug August 3 to 8. Plots 2 and 3 were planted May 20 and dug September 21. Figures 2, 3 and 4 represent graphically the comparative mean weekly soil temperature, air temperature, and soil moisture expressed as per cent of the moisture holding capacity of the soil for all 3 plots. Further details regarding these plots have been previously published (6, p. 70-72).

Results:—Table 12 contains a summary of the results of this experiment. In this table all averages and percentages are calculated on the basis of plants rather than upon the number of seed pieces planted. The differences would be still greater between the inoculated and control rows if the number of seed pieces was used as the basis of comparison. No allowance has been made in the yield records for the lack of competition when hills were missing. Again the differences in yields would be even greater if this were considered. Considerable variation is evident and in the main can be correlated with the methods of inoculation and the conditions under whch the experiment was conducted, as shown in figure 2.

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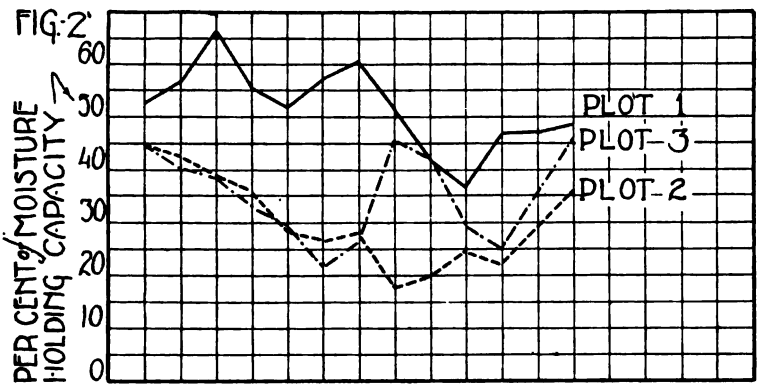

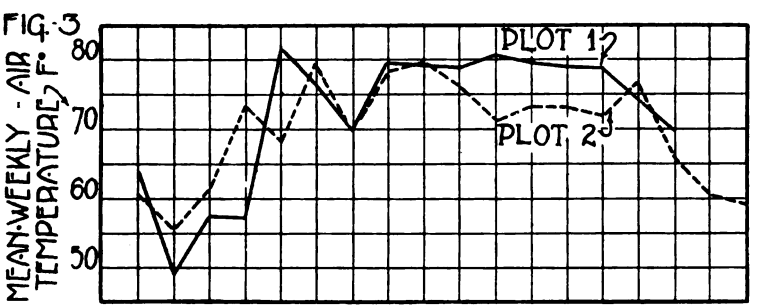

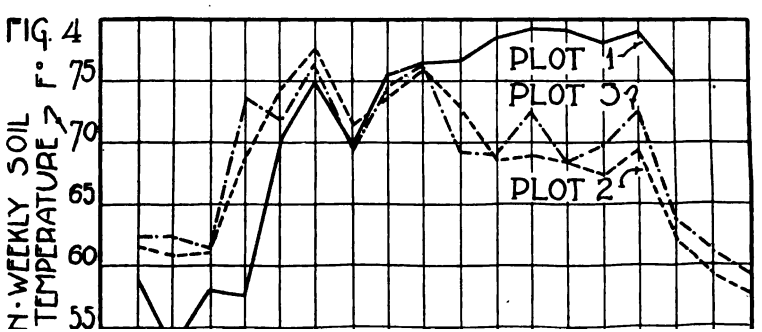

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Germination was decreased by a rotting of the inoculated seed pieces. Very little injury occurred in Plot 1, the only evident decrease resulting from the second method of inoculation. In Plots 2 and 3, the germination of the controls was very poor, but this method of inoculation still resulted in a considerable reduction in stand. The soil temperature in Plot 1 was 5° to 10° below that of Plots 2 and 3 during the first 2 weeks of the experiment and the amount of seed piece decay was considerably less. It was also evident that dipping the freshly cut seed in a spore suspension results in the most rapid progress of the disease.

Very little wilting occurred in Plot 1, while it was very severe in Plot 2. Considerable wilting also occurred in Plot 3. The figures in Table 12 represent plants which completely wilted. The wilting can be correlated with the lower soil moisture and temperature occurring in Plots 2 and 3. It is true that the soil and air temperatures in Plot 1 were higher during the latter part of the experiment and it might be expected that wilting would be more rapid. However, the temperature of the soil in Plot 1 during the latter half of the experiment was slightly above the optimum for the disease as previously determined under control conditions, while in Plots 2 and 3, during the period from the ninth to the fifteenth week when wilting occurred, the temperature was at the optimum for development of the disease. The soil moisture content in Plots 2 and 3 was low enough to accelerate the symptoms of wilt. No great difference in the amount of wilt occurred as a result of the different methods of inoculation.

A considerable number of affected plants failed to produce any tubers. Many of these plants did not show severe wilting in the field. The early progress of the disease resulted in a weak spindling plant which did not require much soil moisture to prevent wilting. The greatest number of barren plants was found in Plot 3, even tho the cultural con-

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Experiment 12—1921

d[1] ent	Number of seed planted	Germination	Plants wilted	Plants barren	Plants with infected tubers	Average weight of all tubers per plant	Weight of infected tubers	Yield based on controls as 100 per cent	
								Total yield	Marketable tubers
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Grams*	*Per cent*	*Per cent*	*Per cent*
1	36	97	3.	20.	75.7	51.0	62.0	27.3	11.2
2	36	89	0.	47.	40.6	16.0	66.0	8.5	2.8
3	37	100	3.	3.	94.6	153.0	85.0	81.8	11.8
ol	217	97	0.	2.	10.3	187.0	5.0	100.0	100.0
1	33	94	74.	6.	90.3	111.0	90.0	29.7	2.8
2	33	33	100.	27.	72.0	43.0	86.0	11.5	1.6
3	33	42	86.	29.	64.3	63.0	75.0	16.8	4.5
ol	220	62	0.	1.	12.5	374.0	5.0	100.0	100.0
1	33	91	46.	40.	50.0	155.0	56.0	15.9	6.8
2	33	21	57.	57.	14.3	117.0	16.0	12.0	10.2
3	33	66	67.	62.	28.6	207.0	66.0	21.6	7.2
ol	219	66	0.	1.	1.4	973.0	0.5	100.0	100.0

1. Made by inserting into seed piece a glass tube containing .5 c.c. spore suspension.
2. Made by immersing freshly cut tubers in a spore suspension.
3. Made by immersing tubers in spore suspension after allowing 3 days for the cut surface to heal.

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pared. The total weight of all tubers produced by the inoculated plants was with one exception less than 30 per cent of that produced by the control plants. This reduction in yield was partly caused by the number of barren plants. In addition many of the tubers were infected with stem-end rot and showed vascular discoloration. With only one exception, more than 50 per cent of the tubers from inoculated plants were infected while the controls averaged less than 5 per cent infection. If the yields of healthy tubers from inoculated plants be compared, using the controls as a basis, the differences would be even more evident. The inoculated rows in all plots yielded only about 8 per cent of the quantity of healthy tubers produced by the controls.

Plot 1 produced the lowest yields, with increasing yields occurring in Plots 2 and 3 in order. The greatest per cent of infected tubers occurred in Plot 2; no consistent difference in the amount of infected tubers produced by the various methods of inoculation was evident in this plot. A considerable decrease in total yield was noticeable, however, with the second method of inoculation.

Comparison of Stem-End-Rot Seed and Inoculated Seed

Experiment 13, 1922

Previous experiments in the greenhouse have shown the possibility of the disease being transmitted by stem-end rot seed. The results, however, were not as conclusive as the greenhouse and field experiments with inoculated seed. The following experiment was conducted to obtain further data on the transmission of the disease by the seed tubers.

Methods:—Healthy Bliss Triumph seed was used as controls. Some of this same seed was inoculated by dipping the freshly cut seed in a spore suspension of *Fusarium eumartii*. The stem-end rot seed was from the same lot as that used in the greenhouse, Experiment 10, in which infection was of various degrees of severity. They were roughly divided into two lots; slight infection and severe infection, consisting of 135 tubers each. In addition, each tuber was halved lengthwise, one-half was planted and the other half retained for detailed notes on the type of disease and for isolation studies.

The experiment was conducted at the Agricultural College, Lincoln. The seed was planted on May 5 and dug on August 21. The mean weekly air temperature and soil moisture content for the period of the experiment were as follows:

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Date	Air Temperature °F.
May 5—May 12	70.1
May 12—May 19	58.3
May 19—May 26	64.2
May 26—June 2	64.8
June 2—June 9	74.0
June 9—June 16	81.1
June 16—June 23	76.3
June 23—June 27	76.0
[2]July 3—July 10	71.8
July 10—July 17	73.6
July 17—July 24	73.5
July 24—July 31	77.7
July 31—Aug. 7	78.4
Aug. 7—Aug. 14	77.5
Aug. 14—Aug. 21	82.3

Date	Soil Moisture[1] Per cent
May 28	57.8
June 5	40.4
June 12	39.4
June 19	37.6
June 26	40.2
July 3	38.6
July 10	45.8
July 17	51.2
July 31	33.2
Aug. 7	32.2
Aug. 14	24.8

Results:—The stem-end rot seed was divided into groups somewhat similar to those recognized in Experiment 10, and an attempt was made to correlate these different types of injury with the kind of organisms isolated. It was found impossible to correlate the types of infection with the presence of any specific organism, and the detailed results will not be presented here. Neither was it possible to correlate the type of infection or the organism isolated with the resulting disease in the field. The cultures yielded *Fusarium eumartii* from only 4 per cent of the tubers, *F. oxysporum* from 4 per cent, *Fusarium* species, chiefly *F. trichothecioides*, from 32 per cent, miscellaneous fungi, chiefly Alternaria, from 19 per cent, bacteria from 45 per cent, and 11 per cent of the cultures were sterile. Usually several organisms were isolated from the same tuber. The tubers yielding *F. eumartii* gave rise to 60 per cent infection of the plants in the field, whereas all other tubers yielding miscellaneous fungi and *Fusarium* species produced only from 10 to 20 per cent infected plants. The reasons for the low number of isolations of *F. eumartii* are discussed in detail on p. 33 and do not need to be reconsidered here.

Table 13 presents the results of the field tests. It was obvious that the inoculated seed pieces produced a higher percentage of infected and barren plants and a lower yield of total and healthy tubers than the stem-end rot seed, and the percentage of germination was also lower. It was found, however, that the severity of the stem-end rot in the seed

[1] Soil moisture is expressed as per cent of the moisture holding capacity.
[2] Temperature records were missing from June 27 to July 3.

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TABLE 13.—*Comparison of stem-end-rot seed tubers and inoculated seed tubers*

Experiment 13—1922

Seed tubers	Number of seed planted	Germination	Plants barren	Plants with infected tubers	Plants producing marketable tubers	Average weight of all tubers per plant	Weight of infected tubers	Weight of healthy marketable tubers	Yield based on controls as 100 per cent	
									Total yield	Marketable yield
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Grams*	*Per cent*	*Per cent*		
Controls	124 (680)[1]	94.4	0.0	11.1	90.5	319	2.0	84.0	100.	100.
Slight stem-end rot	135	75.5	9.8	20.5	72.0	188	11.0	61.0	59.	45.
Serious stem-end rot	135	61.4	15.4	29.7	56.0	148	20.0	52.0	46.	28.
Inoculated	270	55.5	24.6	52.6	18.0	79	64.0	17.0	24.	5.

[1]The percentage of germination of controls was based upon 680 seed pieces. All other data on controls were based upon the individual results of 124 hills.

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could be correlated with the amount of disease and the resulting yield of healthy tubers. Undoubtedly much of the seed contained organisms not isolated in the cultural studies. Examination of the plants in the field showed that the disease resulted in most cases from rotting the seed piece and the advance of the disease up the stem. This does not necessarily mean, however, that the causal organism was always present in the seed. The rotting of the seed due to the action of any one of a number of organisms might permit the entrance of *Fusarium eumartii* from the soil.

Relation of Stem-End-Rot Seed to the Disease

Experiment 14, 1923

Further experiments with stem-end rot seed were conducted in 1923 at various points in western Nebraska to determine if possible the relation of weather conditions to the disease, and the transmission of the disease from stem-end rot tubers.

Methods:—The locations of the experimental plots and the dates of planting were as follows:

Plot A—Planted May 16, Scotts Bluff substation, Mitchell, Nebraska, dry land culture.

Plot B—Planted May 16, Scotts Bluff substation, Mitchell, Nebraska, irrigated.

Plot C—Planted June 8, Scotts Bluff substation, Mitchell, Nebraska, irrigated.

Plot D—Planted June 4, August Gadeken's farm, Bushnell, Nebraska.

All the plots were dug September 15 to 20.

The seed was from a bin selection and contained all types of stem-end rot. Each tuber was cut lengthwise into 4 seed pieces for planting in the 4 plots. Notes were taken on the type of injury and the tubers were divided into 7 different groups based on the type of infection. Notes were made at various times thruout the season and records taken of air and soil temperature and soil moisture.

Results:—The detailed results of this experiment are shown in Table 14. The differences in the various plots are not so evident or consistent as they were in Experiment 12. It must be remembered, however, that the bin-selected stem-end rot seed tubers provided a more variable factor as a basis for the experiment than the inoculated tubers in Experiment 12.

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In addition the environmental conditions thruout the season were rather abnormal. The temperature conditions for Plots A, B, and C were practically the same except that Plot C was planted about 3 weeks later. The mean monthly temperatures for these 3 plots were June 66.7°, July 74.7°, and August 69.5° F. During many weeks of the experiment the temperature was at the optimum for the development of the disease in these 3 plots. The temperature in Plot D was below the optimum for the disease during most of the season, the mean monthly temperatures being—June 64.2°, July 72.6°, August 67.6°. When the mean weekly temperatures were calculated for these plots for the entire period of the experiment, it was found that the temperature of Plot D was consistently 2° to 4° below that of Plots A, B, and C. The rainfall for the months of May, June, July, and August was considerably above normal for all plots. Plot D had a total of 14.11 inches precipitation, which was 59 per cent above normal, while Plots A, B, and C had 13.64 inches, or 39 per cent above normal. As a result of the high rainfall and the differences of the moisture holding capacities of the soil of the various plots, it was found that the moisture content based on the moisture equivalent was less in the irrigated plots during most of the experiment than in the plots with dry land culture.

The results presented in Table 14 show that the disease was not as severe in Plot D, with temperatures slightly below the optimum for the disease, as in the other plots. The low germination in Plot D, however, was due chiefly to poor cultural conditions, as indicated by the controls. Plot C, planted two weeks later than Plots A and B, had a smaller number of plants with infected tubers and a smaller percentage of tubers showing stem-end rot, along with a lower total yield. This was probably due to the fact that this plot was dug at the same time as Plots A and B, and therefore the duration of the experiment was two weeks shorter. These results correspond with many observations made in commercial fields, that is, that early digging of infected fields will often decrease the percentage of stem-end rot tubers.

No correlation could be made in this experiment between the type of infection occurring in the seed and the resulting disease. Therefore, the detailed results are not presented.

No results are presented on the percentage of plants wilting in the field, because a rather severe attack of early blight during August complicated the symptoms and the detailed

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TABLE 14.—*Results of field experiments with stem-end-rot seed*

Experiment 14—1923

Seed	Number of seed planted	Germination	Plants barren	Plants with infected tubers	Plants producing marketable tubers	Average weight of tubers per plant	Weight of infected tubers	Weight of healthy tubers	Yield based on controls as 100 per cent	
									Total yield	Marketable yield
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Grams*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
ntrol.....	50	95.0	0	4.0	98.0	362.	0.7	80.1		
m-end rot.....	218	86.2	4.7	79.2	65.9	427.	44.0	42.6	118.0	62.8
ntrol.....	50	98.5	0	46.0	94.0	454.	8.8	63.0		
m-end rot.....	248	94.7	2.9	80.0	51.0	326.	47.2	35.2	71.8	40.1
ntrol.....	50	94.0	0	14.0	90.0	410	2.6	75.8		
m-end rot.....	248	81.8	6.8	58.6	61.0	290	27.9	50.4	70.7	46.9
ntrol.....	150	71.3	0	3.5[1]	68.4[1]	186.	1.7	64.0		
m-end rot.....	248	63.7	1.2	50.6	60.7	242.	28.0	46.3	130.2	94.3
ntrol.....	300[2]	87.0	0	16.7	86.9	353.	4.3	70.9		
m-end rot.....	962	78.4	4.0	68.4	59.1	321.	38.8	42.8	90.7	55.2

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results are therefore omitted. Slight wilting was rather general, however, in all plots. There were only a few plants that wilted completely, probably due to the high soil moisture content occurring thruout the period of the experiment.

The average for all 4 plots shows the general effect of the disease to be rather severe. The yield of marketable tubers was much less in every plot from the infected seed than from the healthy seed. While the total yield was sometimes greater with the infected seed, it must be remembered that the yields shown in Table 14 are based on the number of plants. If the data were based on the number of seed planted, and the effect of missing hills on the yield of surrounding plants taken into consideration, it would be found that both the total yield and the yield of marketable tubers would be greatly reduced for the stem-end rot seed.

Relation of Infested Soil and Stem-End-Rot Seed to the Disease

Experiment 15, 1923

Previous experiments have shown that the planting of stem-end rot seed resulted in an increase in the disease and a corresponding decrease in yield. The following experiment was planned to determine the effect of soil infestation as well as seed infection on the amount of disease.

Methods:—Two plots were selected on the same farm at Hemingford, Nebraska. One of these plots had not been planted with potatoes for several years while the other had grown a crop of potatoes the previous year which had a high percentage of wilt and stem-end rot. Both stem-end rot and healthy seed were from the same sources as those used in Experiment 14. The stem-end rot seed was divided into groups according to the various types of infection, and corresponding halves of each seed piece planted in each plot. No temperature records were taken at these plots, but the mean temperature was about optimum for the disease or slightly below. The precipitation was above normal thruout the period of the experiment.

Results:—The results of this experiment are presented in Table 15. Comparing the results from infected seed and healthy seed, in both plots, the disease resulted in decreased germination, an increase in barrenness and in the number of infected plants, and an increase in the number of infected tubers, with a resulting decrease in both total and marketable yield. In comparing the two plots it was evident that infested

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TABLE 15.—*Relation of infested soil and stem-end-rot seed to the disease*

Experiment 15—1923

Plot	Seed	Number of seed planted	Germination	Plants barren	Plants with infected tubers	Plants producing marketable tubers	Average weight of tubers per plant	Weight of infected tubers	Weight of healthy tubers	Yield based on controls as 100 per cent	
										Total yield	Marketable yield
			Per cent	*Per cent*	*Per cent*	*Per cent*	*Grams*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
fested soil[1] . . .	Controls.	123	96.0	0	17.0	100.0[2]	793.3	2.6	89.2	100.0	100.0
	Stem-end rot. . .	403	70.0	8.1	40.3	85.8	599.0	15.5	75.9	75.5	64.3
d soil.	Controls.	112	90.0	0	7.7	100.0[2]	434.2	4.4	88.0	100.0	100.0
	Stem-end rot. . .	403	70.0	4.1	42.0	80.0	323.0	20.8	71.6	74.5	60.6

[1]Non-infested soil refers to that not known to have been planted to potatoes for 3 years; it was probably slightly infested.
[2]Based on individual hill counts of 53 control plants (every alternate 5 plants in the row).

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soil caused a considerable increase in disease with a resulting decrease in yields. The healthy seed planted on infested soil showed only a slight increase in the number of infected tubers over the healthy seed on non-infested soil, and the number of infected plants was even less; however, the yield both total and marketable was only about half as great. The total yield of the stem-end rot seed was considerably higher on the non-infested soil and the amount of infection was correspondingly lower. The total yield of the controls on the infested soil was only 74 per cent of that on non-infested soil, while the stem-end rot seed yielded only 54 per cent as much on infested soil. The decrease in yields on the infested soil was partially due to the preparation of the seed bed. In this plot the soil had been planted to oats and was plowed just before planting. The other had been prepared for potatoes earlier in the spring. The results shown in Table 15 are based on germinated seed, but yields based on the number of seed planted would show even greater differences. Because of the high soil moisture content thruout the experiment, complete wilting occurred in only a small number of plants. Slight wilting was very prevalent in plants from the infected seed in both plots. As in previous experiments, the type of infection in the seed piece could not be correlated with the resulting disease.

Discussion of Field Experiments

Different methods of seed inoculations were tested and it was found that immersion of freshly cut seed in a spore suspension of the pathogene resulted in the greatest amount of disease. Allowing such cut seed to callus over for several days before inoculating did not prevent infection, however. Inoculations with 0.5 c. c. of spore suspension in a wound did not reduce germination greatly but did cause considerable disease.

Tests made under different environmental conditions showed that the results of such inoculation experiments could be correlated with the results obtained in the greenhouse under control conditions. High soil temperatures early in the season resulted in a great decrease in germination. A high percentage of wilting occurred when the air and soil temperatures were optimum for the disease and such wilting could be correlated with low soil moisture contents in midseason. The amount of stem-end rot occurring in the tubers could not be correlated with weather conditions. Mean tem-

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peratures below the optimum for the disease decreased the amount of disease.

Experiments with stem-end rot seed showed that such seed could transmit the disease. Stem-end rot seed on non-infested soil yielded about the same as healthy seed on infested soil.

Both stem-end rot seed and infested soil caused the same type of disease as that produced by inoculating the seed, altho the amount of disease was not as great. No correlation could be made between the type of infection in the stem-end rot seed and the resulting disease, nor could either of these be correlated with the organisms isolated from such seed tubers.

The disease resulted in decreased germination, increased barrenness, a large number of plants producing infected tubers, and a decreased total yield, with a high percentage of stem-end rot tubers.

With a high soil moisture content the wilt symptoms were not very evident, but the disease under these conditions often resulted in a large number of stem-end rot tubers such as occurred in the greenhouse under controlled conditions. Early digging tended to decrease the amount of stem-end rot in the tubers.

It was evident from these experiments that the disease can be transmitted by either infested soil or seed. Even when the seed tubers did not yield *Fusarium eumartii* in culture, it was evident that such seed produced a weaker plant which was apparently more susceptible to infection from the soil. The only control measure which recommends itself is the use of disease-free seed on non-infested soil, with early digging of affected plants.

RELATION OF TEMPERATURE AND RELATIVE HUMIDITY TO TUBER ROT IN STORAGE

Preliminary Tests

Healthy Bliss Triumph tubers were inoculated by introducing the inoculum into a small wound, and others were inoculated by dipping unwounded tubers in a spore suspension of the pathogene. These tubers were placed in desiccators containing sulphuric acid in concentrations necessary to obtain a range from 20 to 100 per cent in the relative humidity. The tops were sealed and the desiccators were placed at a temperature of 25° C.

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It was found that infection occurred only when the tubers had been wounded. The lack of aeration in the containers resulted in considerable black heart, and apparently inhibited the progress of the pathogene so that no differences could be noted at the various relative humidities employed.

Further tests were made to determine whether or not *Fusarium eumartii* was capable of penetrating the unwounded epidermis of the potato tuber. These tests were made by treating healthy tubers with a solution of mercuric chloride, washing them in sterile water, and placing them in moist chambers at 25° C. after making the following treatments:

1. Tubers wounded with sterile scalpel by making a cut ¼ inch deep.
   (a) Tubers immersed in a spore suspension of *F. eumartii.*
   (b) One sq. cm. of an agar culture of *F. eumartii* was inverted over the wound, with the mycelium in contact with the tuber.
2. Tubers unwounded.
   (a) Same as above.
   (b) Same as above.

Infection occurred with both methods of inoculation in wounded tubers, but no infection was ever obtained in unwounded tubers.

Tuber Inoculations

Experiment 16, March 28—May 11, 1923

In this experiment an attempt was made to study the pathogenicity of *Fusarium eumartii* on tubers at various temperatures and relative humidities, and also to allow for sufficient aeration to eliminate black heart and to produce more normal conditions than were present in the preliminary tests.

Methods:—The experiment was conducted at 5 different temperatures: 5°, 10°, 15°, 20°, and 25° C., with 4 relative humidities at each temperature.

The principle employed in the preliminary tests of using solutions of sulphuric acid in varying concentrations to give the desired relative humidity was again used. Large battery jars were employed containing 750 c. c. of sulphuric acid at the necessary specific gravity to give 10.5, 38.0, 70.4 and 100.0 per cent of relative humidity. To allow for aeration the jars instead of being sealed were closed with a thick cotton pack covered with cheesecloth. This provided for a sterile atmosphere without asphyxiating the tubers. It was expected that the specific gravity of the solutions would change

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considerably during the experiment and thus change the relative humidity but by using only 4 degrees of saturation deficit it was hoped that this change would not result in overlapping. At the end of the experiment the concentration of the sulphuric acid was determined with Twaddell hygrometers, and the specific gravity and saturation deficit calculated. The following changes were found to have taken place.

PER CENT RELATIVE HUMIDITY

Initial	Final				
at all temperatures	5°	10°	15°	20°	25°
Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
70.4	69.8	68.0	64.9	62.7	62.7
38.0	42.5	42.5	44.4	41.0	49.0
10.5	14.0	19.0	20.0	22.4	23.9

Altho the above data show that the change in the relative humidity in each set at different temperatures was considerable, the extremes did not overlap and the same relative position of the series remained. The set at 100 per cent relative humidity remained constant.

All tubers used were treated with $HgCl_2$ and washed in sterile water. Four tubers were placed in each jar. Two tubers were inoculated by making a small hole with a cork borer, 3x5 mm. in the side of the tuber and placing in this cavity 2 drops of a spore suspension of *Fusarium eumartii* from a 10-day old culture on hard oat agar. The other two tubers were inoculated by inserting spores and mycelium into a small wound made with a sterile scalpel at the stem end of the tuber. Immediately after inoculating, all tubers were put in the jars, which were then placed at the various temperatures.

Results:—The results of this experiment are presented in Table 16. The amount of rotting was about the same with both methods of inoculation. The greatest amount of rot occurred at 25° C. with 100 per cent relative humidity (Plate 2). At 70 per cent relative humidity the extent of rot was about the same as at 100 per cent. There was a decided decrease, however, at the lower humidities. At 10° rotting occurred at the 3 highest relative humidities while no infection took place at 10 per cent. No infection occurred at 5° at any humidity, and the results at this temperature are therefore not recorded in Table 16; the fungus developed in the wounded tissue but seemed unable to penetrate the healthy tissue.

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TABLE 16.—*Relation of temperature and relative humidity to the rotting of tubers in storage*

Experiment 16

Extent of rotting expressed in mm. diameter of rot (surface x depth)

Method of inoculation	25° C.				20° C.				15° C.				10° C.			
	100%	70%	40%	10%	100%	70%	40%	10%	100%	70%	40%	10%	100%	70%	40%	10%
By wound at stem-end.....	40x20	40x25	Complete	30x30	20x12	15x10	15x10	20x20	13x7	15x10	5x4	4x4	12x8	10x12	15x4	No infection
	40x30	40x35	30x30	30x30	20x15	15x12	15x10	15x10	13x7	13x 7	10x4	7x10	12x8	10x8	10x5	
By placing 2 drops of a spore suspension in cavity..	Complete	47x45	27x25	27x25	22x12	22x10	17x12	15x5	12x10	12x5	0	1x1	10x2	7x5	7x1	
	Complete	42x35	Complete	37x15	17x15	27x15	15x5	Contaminated	10x10	Contaminated	0	0	10x2	3x7	7x1	

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All tubers in the experiment except those completely rotted showed healthy eyes and in most instances the sprouts were well started. No fungus growth occurred on the surface of the potatoes except at complete saturation. In most cases a large cavity was formed, and this cavity was surrounded by an interwoven mass of fungus hyphae and starch grains.

In general, an increase of 5° C. in temperature resulted in as great an increase in rotting as an increase from 10 per cent relative humidity to saturation at any specified temperature. We may conclude from this experiment that the control of this rot can be obtained by submitting tubers to a temperature of 5°, or even slightly higher temperatures provided the relative humidity is low.

Stem-End-Rot Tubers

Experiment 17, January 21—March 21, 1923

In this experiment, tubers showing various types of stem-end rot obtained from wilted hills in the field[1] were submitted to different temperatures and relative humidities to determine if possible the effect of these factors on the advance of the disease.

Methods:—The temperatures used were 5°, 10°, 15°, 20°, and 25° C. Three relative humidities, 20, 60, and 100 per cent, were obtained at each temperature as in the previous experiment. At the end of the experiment the solutions were again tested and the low relative humidity set was found to vary from 20 to 30 per cent, the 60 per cent varied from 50 to 60 per cent, and the 100 per cent remained constant.

Each tuber used was carefully examined for external evidences of stem-end rot, and notes taken. Twenty-five whole tubers were submitted to various temperatures and relative humidities. Seventeen other tubers were halved and notes taken on the type of internal injury. The cut surfaces were

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showed any increase in the external appearance of the disease. It is possible that the disease advanced internally and could not be detected on the outside.

Eleven of the 17 halved tubers showed a distinct increase of infected tissue. Four of the 11 halved tubers placed at various humidities at 5° and 10° showed no advance in rotting while the other halves of these 4 tubers when placed at corresponding relative humidities at 25° C. showed a distinct advance, and in 2 of these complete rotting occurred. At 15° a slight advance in rotting occurred in 2 of the 3 halves used, while the other halves at corresponding relative humidities at 25° showed a much greater increase; in one instance complete rotting occurred. At 20°, one halved tuber showed a slight advance of rot at 100 per cent humidity and one at 20 per cent showed no increase. The other halves placed at corresponding humidities at 25° underwent complete rot. Two halves placed at 20 per cent saturation at 20° and 25° showed a slight advance, while the other halves at 100 per cent saturation rotted completely at these temperatures.

It was evident from this experiment that stem-end rot and internal discoloration produced in the field may increase in extent when placed in storage with conditions favorable for the disease. A temperature of 10° C. or below was sufficient to hold the disease in check under all conditions of relative humidity. In the previous experiment with inoculated tubers this temperature prevented the advance of the disease only with a low relative humidity. Temperatures higher than 10° tend to increase the extent of rotting in infected tubers in proportion to the increase in temperature, up to 25°. Temperature is more important than relative humidity altho as the humidity approaches saturation more favorable conditions for the disease are afforded.

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PLATE 1

Tubers showing various types of stem-end rot and vascular discoloration, All these tubers were produced on wilted plants which had been inoculated with pure cultures of *Fusarium eumartii*.

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PLATE 1

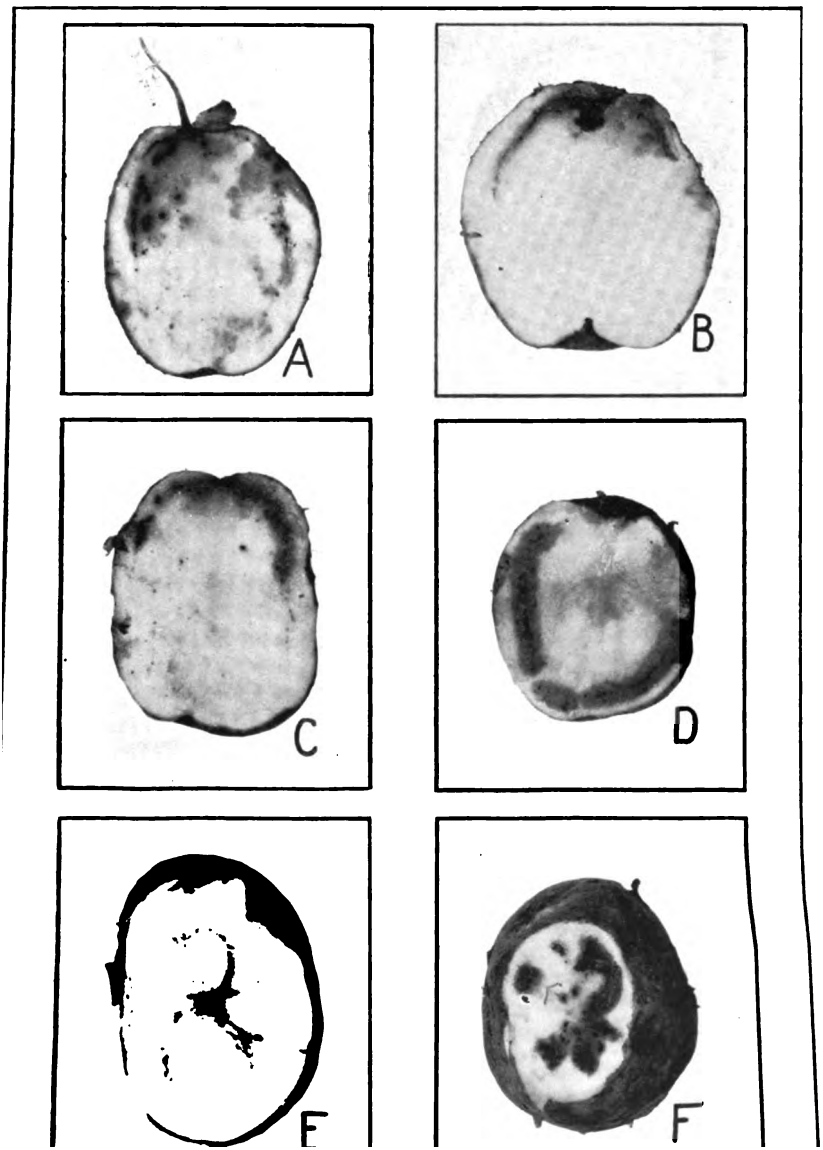

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PLATE 2

Tubers inoculated with *Fusarium eumartii* and placed under the following conditions of temperature and relative humidity, for 6 weeks. Experiment 16, p. 78.

A.—25° C.—10 per cent relative humidity.

B.—20° C.—10 per cent relative humidity.

C.—15° C.—10 per cent relative humidity.

D.—25° C.—100 per cent relative humidity.

E.—20° C.—100 per cent relative humidity.

F.—15° C.—100 per cent relative humidity.

G.—10° C.—100 per cent relative humidity.

Other tubers in Experiment 16 showed degrees of injury midway between the extremes shown here.

Tubers A and B are typical of stem-end rot tubers as they sometimes occur in the field, without any vascular discoloration.

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PLATE 2

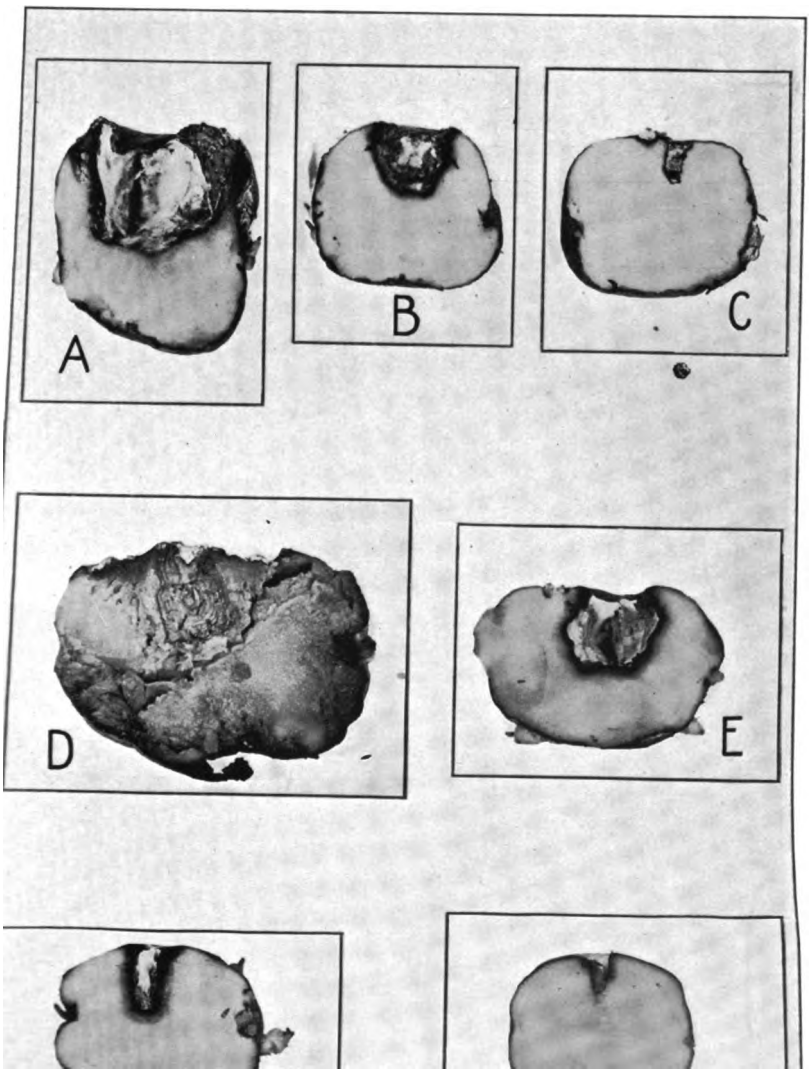

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PLATE 3

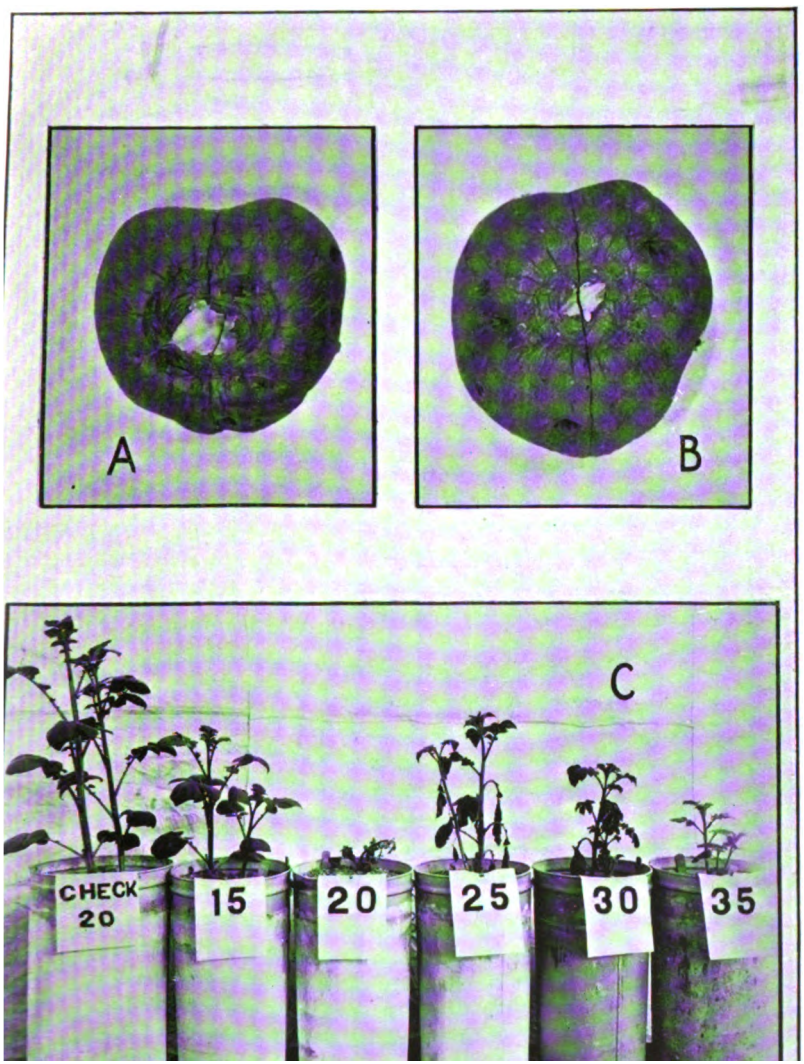

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PLATE 4

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PLATE 5

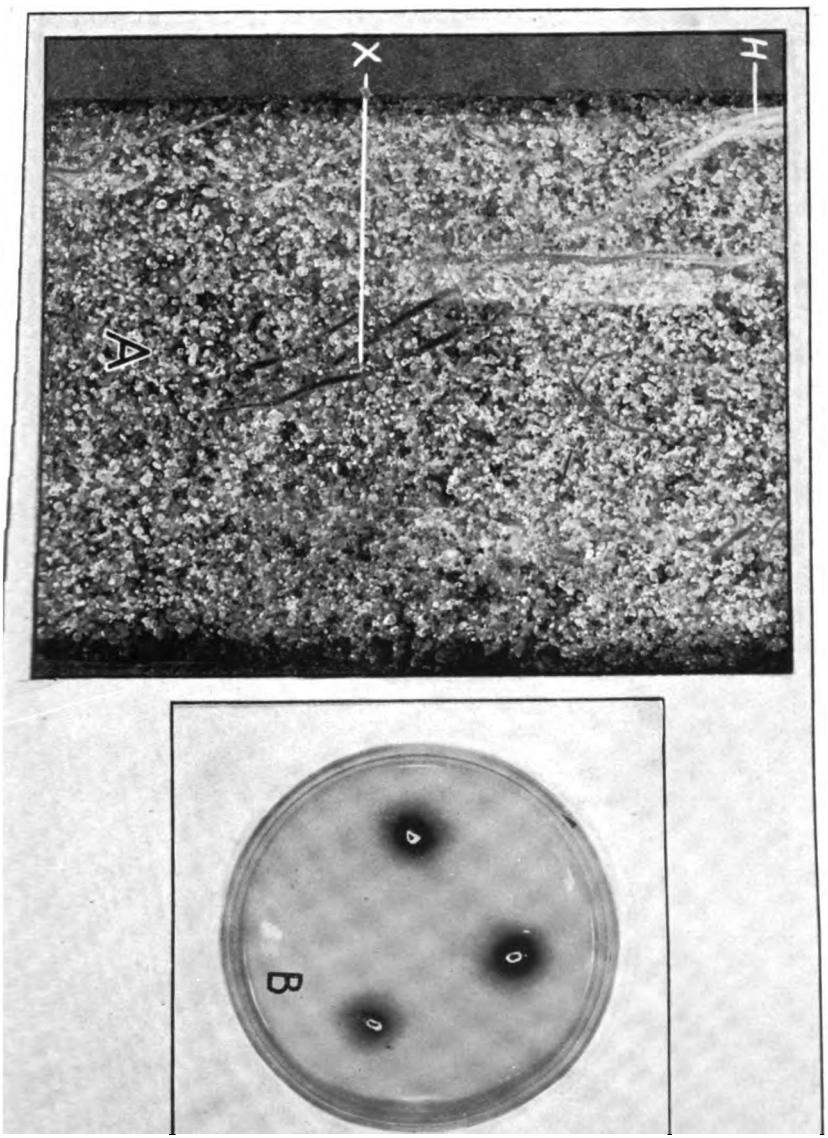

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PLATE 6

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PLATE 7

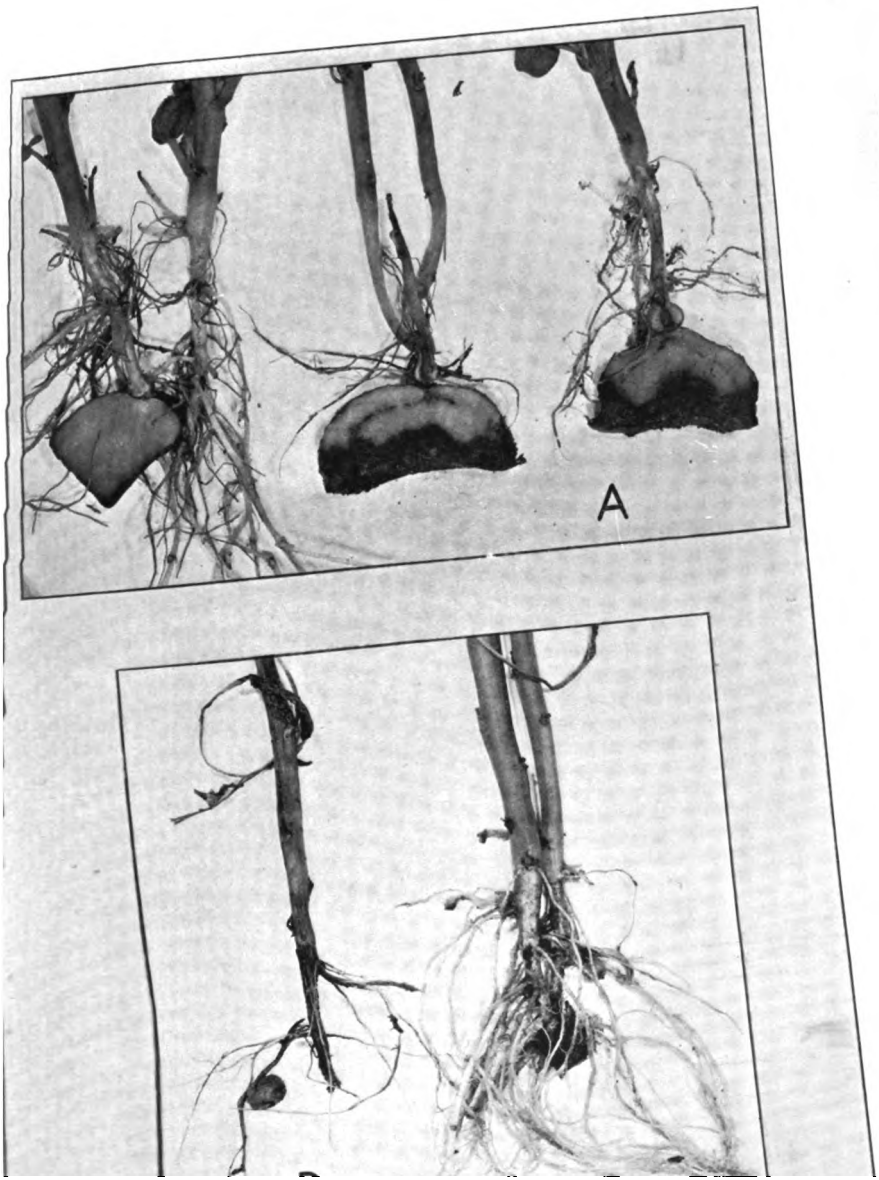

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PLATE 8

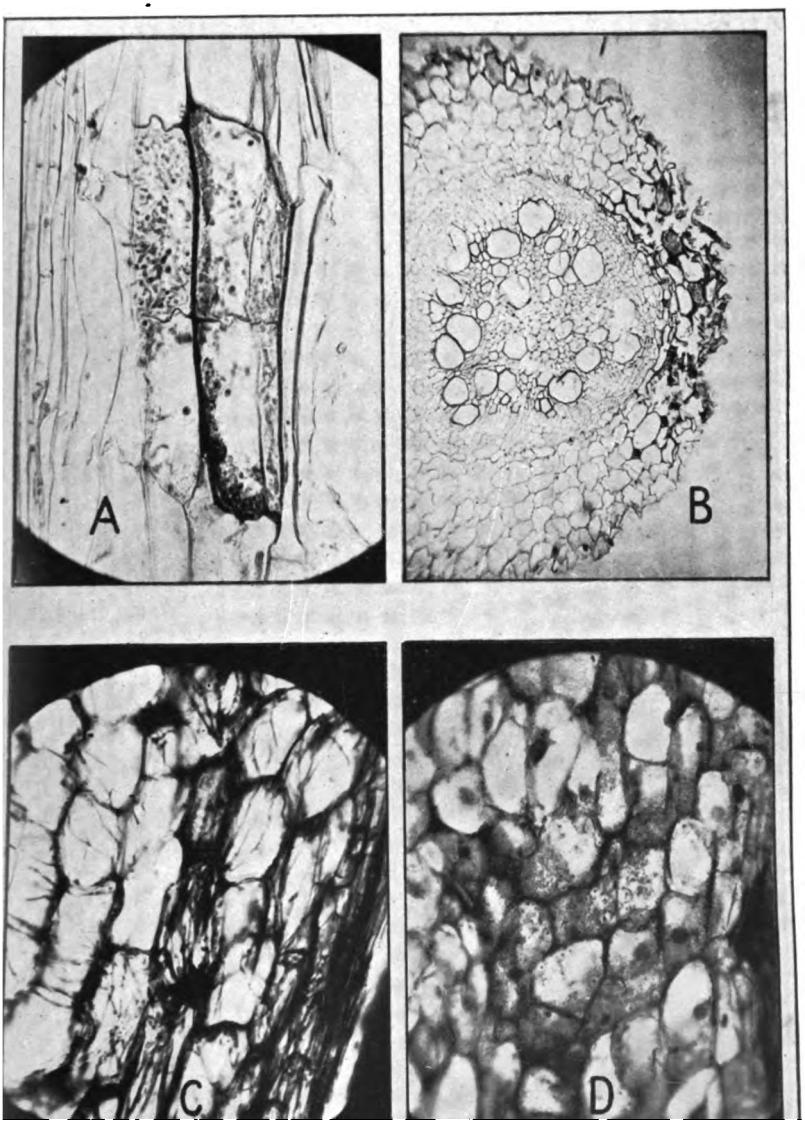

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PLATE 8

A.—Tangential section thru a small root showing the outer cells containing the organism. x 240.

B.—Transverse section of infected root showing the disintegration of the cortex in advance of the organism which could not be detected in this section. x 66.

C.—Tangential section of stem at base of an infected root. The vascular cylinder of the root is indicated at the extreme right. The organism was abundant in the cortex at this point. x 165.

D.—Tangential section of potato tuber showing necrosis of the cells and the presence of the deep staining granular substance. A strand of vascular tissue is indicated at the extreme right. x 145.

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PLATE 8

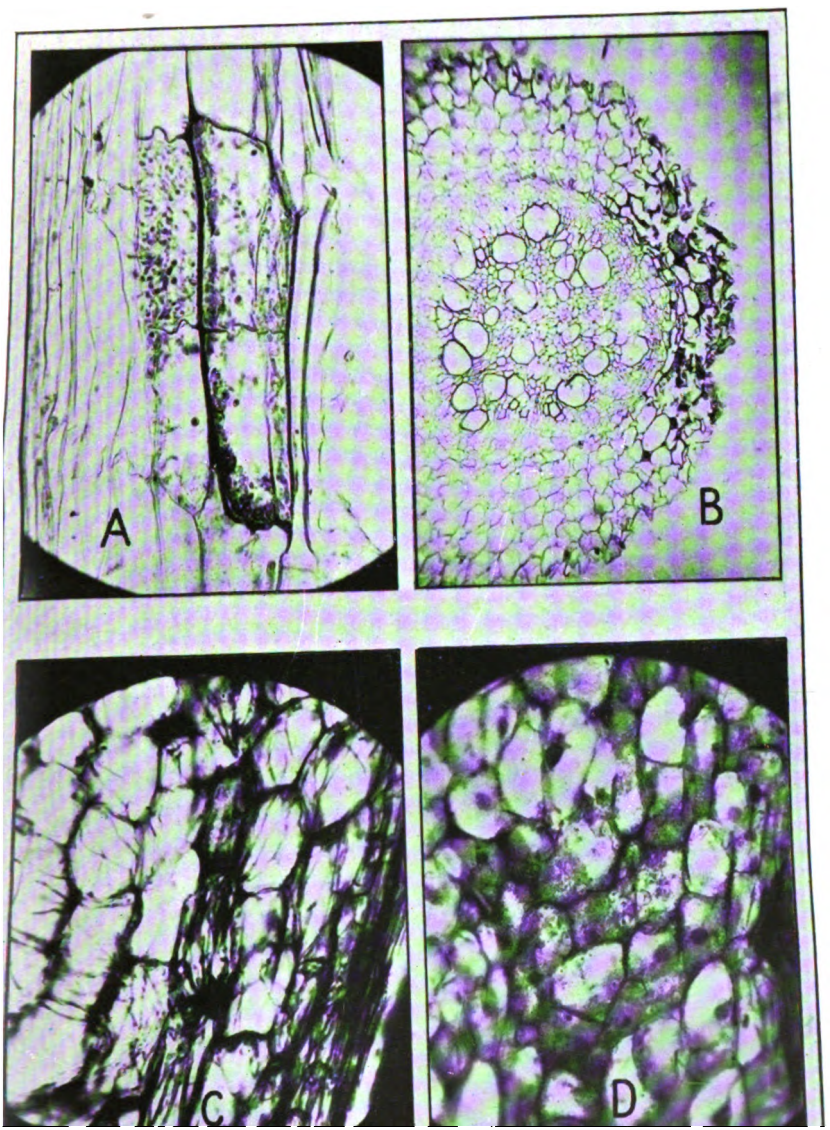

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PLATE 9

A.—Transverse section thru a vascular bundle of the stem 2 inches above point shown in Plate 8, C. The organism could not be detected at this point. Necrosis of the cambium and phloem is apparent, however, in advance of the organism. x 50.

B.—Another bundle of the section shown in A with necrosis of the xylem tissue, x 185.

C.—The third bundle of the section shown in A and B, with necrosis of the external phloem. x 72.

D.—Tangential section thru the pith 6 inches above point shown in A, B, and C. The disintegration of the pith cells in advance of the organism is shown with the thickening of the cell walls and the presence of the granular substance which stains deeply as does the cell walls. x 145.

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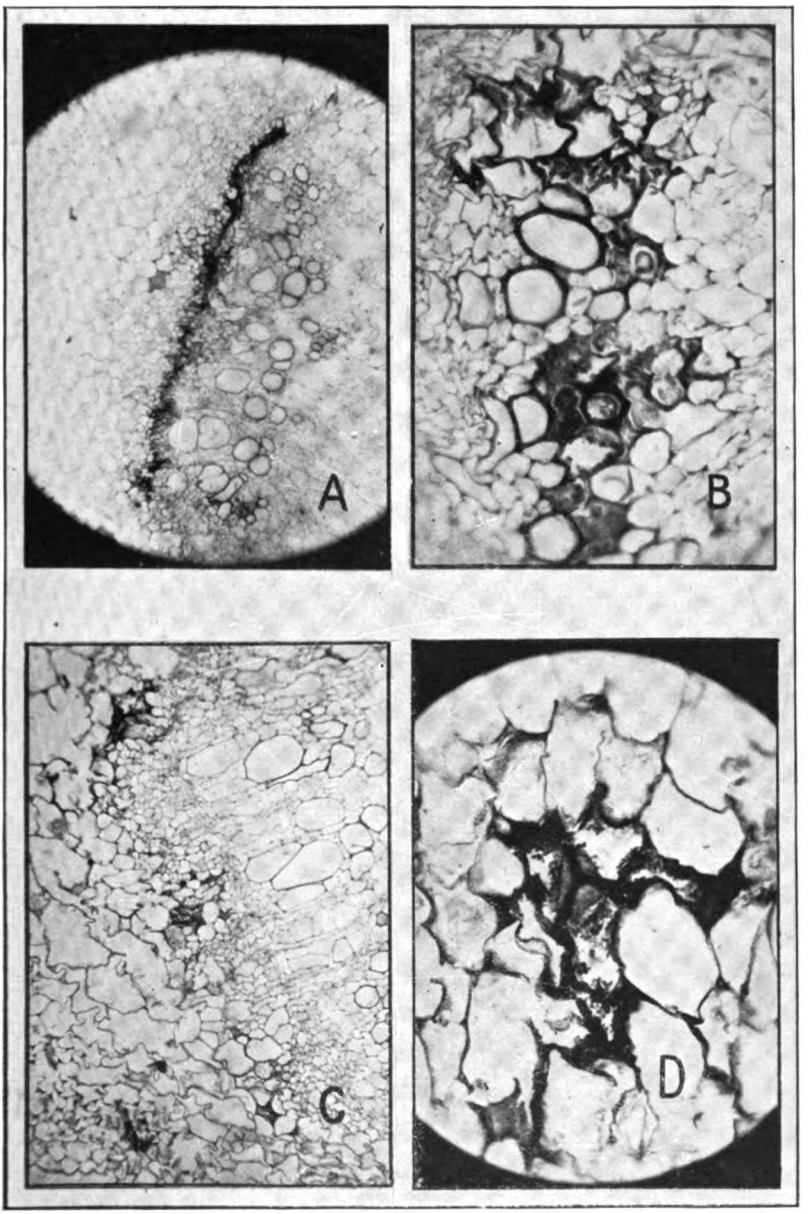
PLATE 9



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COLLEGE OF AGRICULTURE UNIVERSITY OF NEBRASKA
AGRICULTURAL EXPERIMENT STATION
RESEARCH BULLETIN 28

Control Equipment for the Study of the Relation of Environment to Disease

GEORGE L. PELTIER
and
R. W. GOSS
DEPARTMENT OF PLANT PATHOLOGY

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Control Equipment for the Study of the Relation of Environment to Disease

GEORGE L. PELTIER AND R. W. GOSS[1]
DEPARTMENT OF PLANT PATHOLOGY

INTRODUCTION

The investigation of certain plant disease problems in Nebraska has necessitated the study of the relation of various environmental factors to these diseases. The control of these environmental factors in the greenhouse studies has been obtained by the use of previously described apparatus or their modification and adaptation, along with new methods which have been devised to meet the needs of these investigations. In view of the widespread interest in the subject of environmental control for experimental studies, it was deemed advisable to present briefly the methods now in use in this department in the hope that the information may be of assistance to workers in other institutions.

The authors were exceptionally fortunate in having had an opportunity, before coming to Nebraska, of using the apparatus and methods employed for such studies in other institutions; one of the authors having been familiar with the methods used by Dr. James Johnson and Dr. L. R. Jones and his staff at the University of Wisconsin in controlling soil temperatures and the other with the methods used by Dr. C. F. Hottes at the University of Illinois in the control of air temperatures and other factors. The apparatus and methods described in this paper are largely a combination and adaptation of the above methods, with the exception of the control of low temperatures.

The chief aim of the authors in their investigations has

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treme accuracy of control for simplicity and low cost. The authors believe that the control of temperatures within a range of 1° to 2° C. is all that is essential in most greenhouse experiments; if more accurate control is necessary, more expensive equipment is essential and more time must be spent in its regulation. The equipment described in this paper has been used for several years and has been found to be accurate enough for the problems under investigation. It can be operated for the most part by a trained greenhouse man, thus relieving the investigator for other necessary work.

GREENHOUSE CONTROLS

For all experimental studies requiring considerable space and where great accuracy of temperature control was not essential, the usual steam heated greenhouses have been used. By the use of Johnson Service Co. thermostatic steam controls and careful ventilation, the temperature of each greenhouse can usually be kept within a range from 2° to 3° C. In this way, a series of greenhouses at different temperatures ranging from 15° up to any desired higher temperature can be obtained from October 1 to May 1 in this climate.

Apparatus for the more accurate control of soil and air temperatures as described in the following pages can also be placed in any of the greenhouses having a temperature slightly below that desired in the control apparatus.

Low temperature greenhouse.—In order to accurately control temperatures below 20° C. during most of the year, it has been found necessary to use artificial refrigeration. The principle employed was that of cooling a large room by refrigeration to a temperature below that required, and to install electrically heated and controlled soil and air temperature cases and incubation chambers for the desired temperatures in this room. For this purpose a portion of a greenhouse was walled off into a room 8 feet wide by 25 feet long. A double glass wall and roof having 2 inches dead air space were installed

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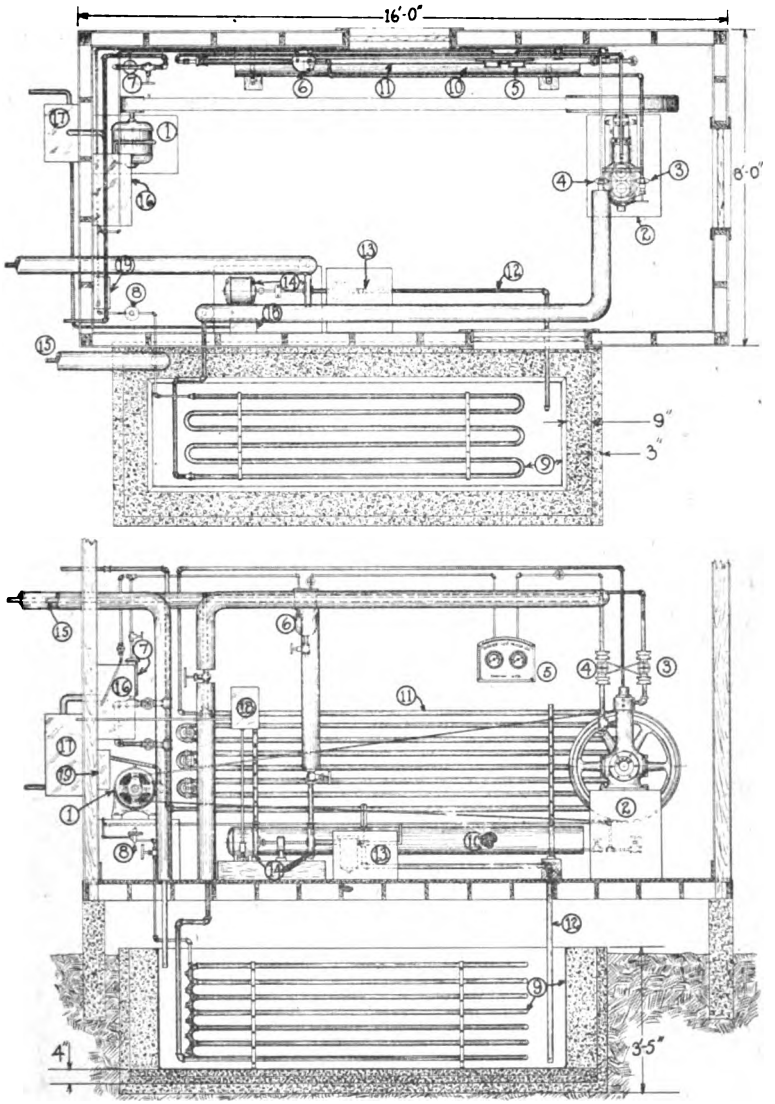

FIG. 1.—DETAILS OF COMPRESSOR ROOM AND BRINE TANK.

1. Motor. 2. Two-cylinder Baker compressor. 3. Main discharge valve. 4. Main suction valve. 5. Gauge board. 6. Oil trap. 7. Automatic water valve. 8. Automatic ammonia expansion valve. 9. Steel brine tank and brine tank coils. 10. Liquid receiver. 11. Condenser. 12. Brine discharge line. 13. Thermostatic temperature regulator for brine. 14. Brine pump and motor. 15. Brine return line. 16. Automatic controller for starting and stopping motor. 17. Main switch. 18. Brine pump motor switch. 19. Switch for fan in low temperature room.

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and various automatic control devices. The electric controller (figure 1, 16), for automatically starting and stopping the compressor motor, is put into operation by closing the line switch. This controller is equipped with a low voltage and overload release. An electric thermostat (figure 1, 13) is immersed in the brine line between the tank and the brine pump, and is connected to the electric controller so that the ammonia compressor is started and stopped to maintain the brine within a 5 degree centigrade range of the temperature for which it is set. An automatic valve (figure 1, 7) is installed to control the flow of water thru the ammonia condenser, according to the pressure of the ammonia therein. As the pressure of the ammonia rises, the valve opens wider. As the pressure drops the valve closes, so that when the compressor is shut down the flow of water is cut off entirely. The pressure of the ammonia in the condenser also actuates the electric controller (figure 1, 16) in order to shut down the compressor should the pressure rise too high, due, say, to failure of cooling water. An automatic expansion valve (figure 1, 8) is installed to control the flow of liquid ammonia from the receiver (figure 1, 10) to the cooling coils in the brine tanks (figure 1, 9). This expansion valve is operated according to the pressure of the ammonia in the cooling coils.

The steel brine tank, 10 x 2½ x 3 feet, is set in a concrete pit and well insulated with granulated cork as shown in Figure 1, 9. This tank contains 375 feet of low pressure ammonia coils surrounded by the calcium chloride brine. The brine is pumped thru about 750 feet of coils placed in a well insulated bunker about 20 feet long adjoining the low temperature room in the greenhouse. These coils are arranged in a staggered manner (figure 2, 9), so that by means of valves the brine can be circulated in every alternate coil. During a period of low outside temperatures, only one set of coils is turned on. It is only during warm days and bright sunshine that both sets of coils are used. A large steel pan placed under the coils catches the drip from the coils, which is drained off.

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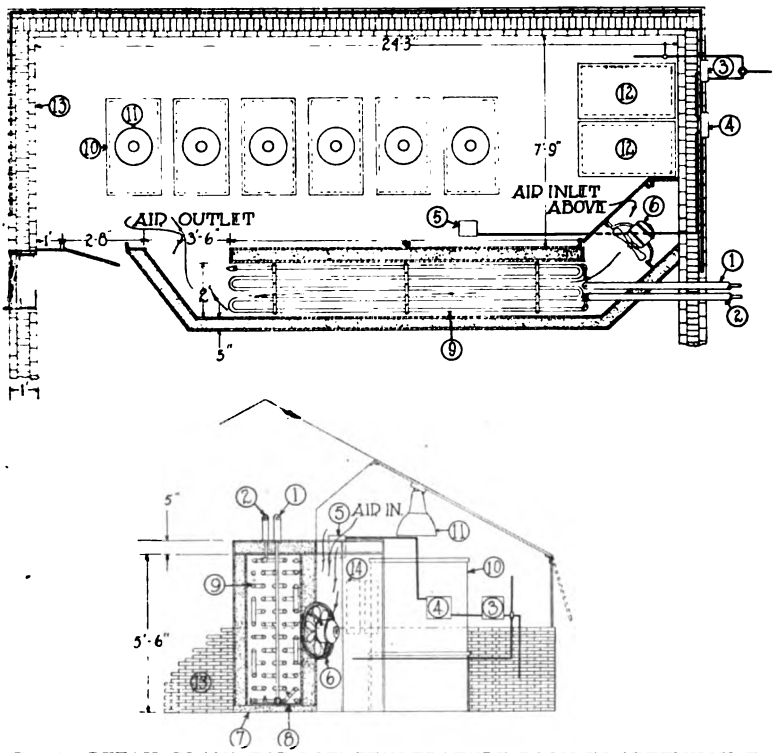

FIG. 2.—DETAIL PLANS FOR LOW TEMPERATURE ROOM IN GREENHOUSE

1. Cold brine intake. 2. Warm brine return. 3. To switch in compressor room. 4. Magnetic switch control of thermostat. 5. Electric thermostat. 6. I. G. L. self cooled 24" fan. 7. Well insulated bunker. 8. Drip pan. 9. Brine coils. 10. Temperature cases. 11. Bowl reflectors and electric lights. 12. Incubation chambers. 13. Brick wall of greenhouse. 14. Door into fan chamber.

and discharges the air at the opposite end of the bunker into the low temperature room. By measurements with an anemometer it has been found that about 2,000 cu. ft. of air per minute is circulated over the brine coils. The fan is controlled by an electric thermostat placed in the center of the room about 5 feet high. This control works on a range of 2° to 3° C.

By means of this equipment it has been found possible to maintain temperatures below 5 ° C. from October 1 to May 1. The chief difficulty encountered in controlling low temperatures has been the effect of bright sunlight on the glass roof rather than the effect of high outside temperatures. The effect of sunlight makes it very difficult to maintain a constant

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temperature altho it is possible to maintain a temperature as low as 2° to 5° (plate 1, C.) by the additional use of removable cheesecloth shades on the roof during certain periods of the day.

The authors have found it desirable to conduct practically all their experiments within the electrically heated and controlled temperature cases installed in this room (plate 1, A). Thus it is possible to allow the temperature of the room to drop as low as it will during the night so that a considerable rise in the temperature during the day will not bring the maximum temperature above 5 ° C., which was the lowest temperature maintained in the temperature cases. During cold weather the greenhouse ventilator can be opened and the brine pump shut off; in this way a very low temperature is obtained in the greenhouse (plate 1, B) and the temperature of the brine tank is lowered to about -25° thus establishing a reserve of refrigeration capable of preventing any great rise in temperature during the day even with intense sunlight.

The above apparatus differs from other possible types of refrigeration, chiefly in two ways. First in the type of refrigeration, *i. e.*, indirect ammonia system rather than the direct ammonia, the carbon dioxide, or the sulphur dioxide systems. Second, in the refrigeration of a large room and the use of electrically heated and controlled temperature cases placed in it, instead of the direct refrigeration of the individual temperature cases in which the plants are to be grown. These methods have been used because it is considerably easier to accurately control electric heating units than it is to control refrigeration. In this method, it is also possible to allow the temperature of the room to drop as far as possible during the night, thus allowing for considerable increase during the day when the refrigerating plant is under its peak load. The chief advantages of the type of refrigeration machine used lie in its

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CONTROL OF SOIL FACTORS

Soil moisture.—In conducting experiments involving the control of the soil moisture content, the authors have not considered it practical to attempt to maintain a constant soil moisture content by the use of atmometers or by other methods often employed. Inasmuch as there is not any great effect on disease phenomena in most instances with a very slight change in the soil moisture content, extreme accuracy of control was sacrificed for increased population which is not usually possible with the more accurate methods.

Two types of containers have been used. In experiments in which the plants are to be grown in soil temperature tanks or soil and air temperature cases as described in the following pages, a galvanized iron container, made to fit the temperature apparatus, is used, as shown in Figure 3. These containers hold 10 to 12 kilos of soil. In experiments conducted in the open greenhouse, 3-gallon earthenware crocks are employed holding about 12 kilos of soil.

Enough soil is prepared in the fall to complete one season's experiments. The soil-moisture equivalent is determined from composite samples and at the start of each experiment the soil moisture content (dry weight) is determined. All soil moisture contents are based on the moisture equivalent, as this standard has been found much more reliable in the accurate duplication of experiments than the old method of determining the moisture holding capacity.

The surface of the soil is usually covered with about 1 kilo of coarse gravel or sand to decrease evaporation and prevent fluctuating temperatures of the surface soil. Various other materials have been tried but have been found to be more expensive and less satisfactory. Water is added partly on the surface and also by the use of a reservoir consisting of a small inverted clay pot filled with gravel, placed several inches deep, which is fitted with a glass tube extending several inches above the surface of the soil. By these methods the soil moisture has been found to be very well distributed thruout the container.

The amount of water to be added is determined by frequent weighings. The plants are watered frequently enough so that usually not more than 100 to 150 c. c. of water is required. Thus the departure from the desired soil moisture content is not greater than 1 per cent dry weight.

This method has been found very practical and its use has yielded considerable information regarding disease phenomena.

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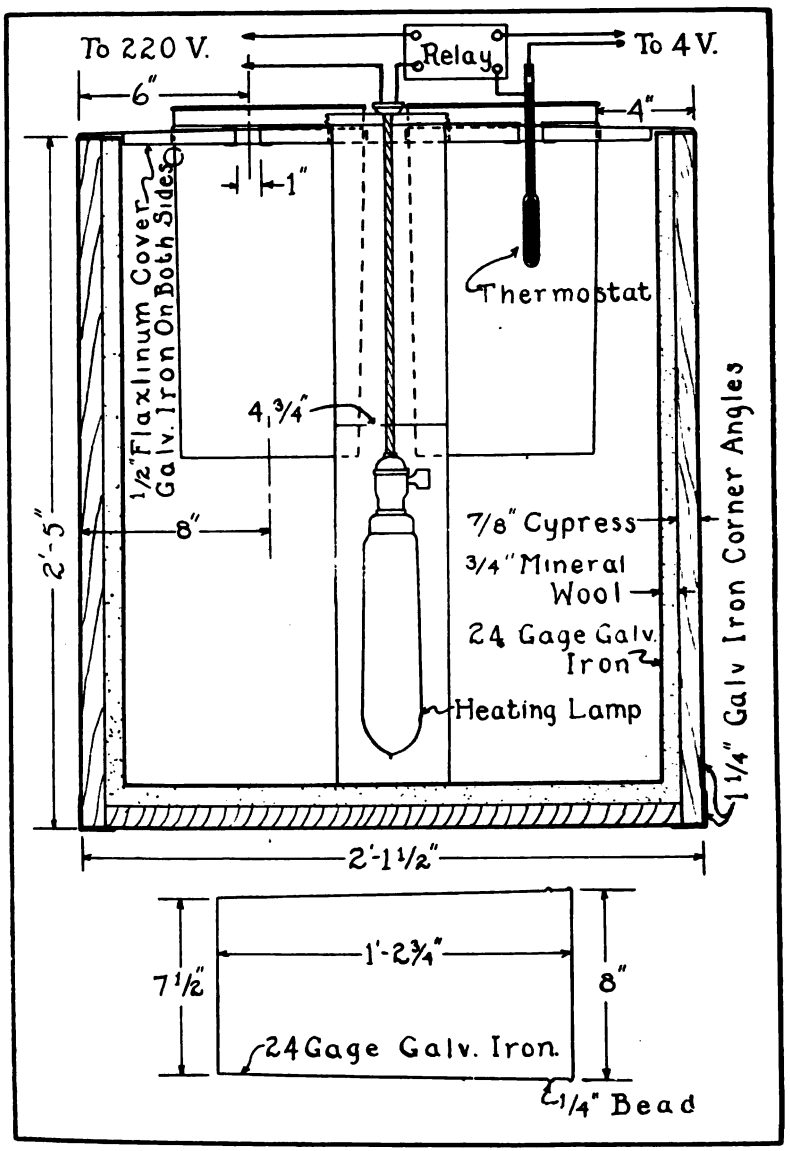

FIG. 3.—Section of soil temperature tank showing construction and arrangement of apparatus.

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Soil temperature.—The control of soil temperatures has been obtained by the use of the "Wisconsin soil temperature tanks." Slight modifications in these "tanks" have been made to meet the local needs but the principle employed is essentially the same. In these "tanks," which are in reality well insulated water baths, the plants are grown in the containers previously described, which are immersed in the water to a level with the surface of the soil. The standard "tank" employed in our experiments is shown in detail in figure 3. The water is heated by a 250 or 500 watt electric heating bulb or other heating appliances. These heating units are controlled by a mercury thermostat, which is immersed in the water. A small amount of glycerine is placed on top of the mercury in the capillary tube to prevent oxidation and decrease capillarity. This thermostat is connected with the heating units thru a 50 ohm pony relay, with the points reversed, which is controlled by a storage battery. This entire apparatus is cheap and efficient and is accurate within a range of 1 ° C. on either side of the desired point. If greater accuracy is required, other types of water thermostats can be used, usually at a greatly increased cost.

These tanks can be used in one greenhouse when the same air temperature is desired; or they can be moved to different greenhouses, thus obtaining a combination of different soil and air temperatures.

CONTROL OF ATMOSPHERIC FACTORS

Air temperature.— For the control of air temperature, glass cases which fit on the soil temperature tanks were built. The frame was constructed of clear well-seasoned white pine. Doors almost the full width and height of the case were placed at both ends allowing easy access to the interior. A dead air space of 1½ inches was obtained by the use of double glass walls. A thick layer of felt was nailed to the bottom frame of the case (figure 4).

The heating elements were made as follows: Twenty feet of chromel wire (No. 24) was wound on a narrow strip of transit and fastened to a large piece of the same material. One heater was placed on each side of the case and they were connected in series. A small pilot light was connected in parallel with the heaters. A Johnson Service Co. electric thermostat was connected in parallel with the heaters and suspended in the center of the case. The thermostat works thru a 50 ohm pony relay with the points reversed, which was connected to a storage battery. The pony relays and storage

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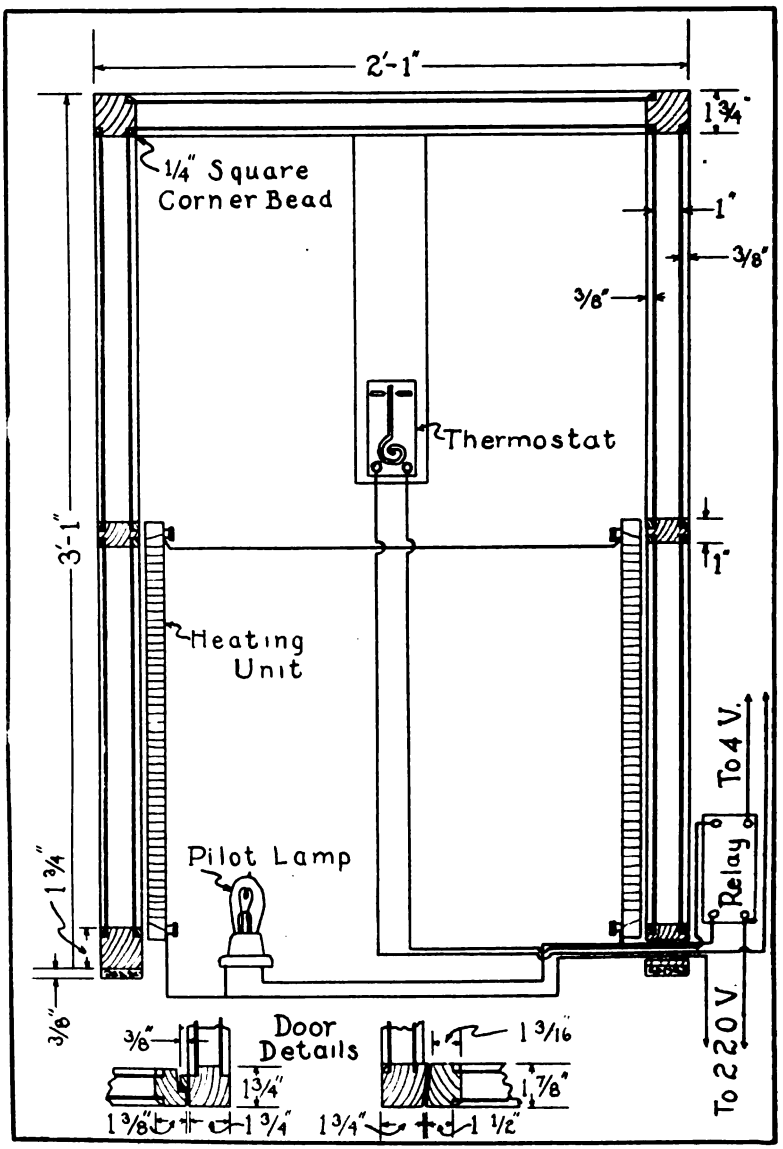

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battery are not as satisfactory as the Johnson Service Co. special relays which are connected directly to the main line; the latter, however, are more expensive.

This equipment has given very satisfactory results. Like the soil temperature tanks the air temperature cases are standard and can be moved from one greenhouse to another.

Light.— During the season of the year that the control equipment is in operation in the greenhouse, the sunlight both as regards the duration and intensity is the most variable factor. In order to supplement sunlight during cloudy days or to increase the duration of light, artificial light was used.

Large bowl reflectors (17 in. diameter) together with 1000 watt nitrogen filled lamps (Mazda C) were placed at a height of 2 feet above the temperature cases. As installed these lights produced approximately 450 foot-candles inside the cases.

On several of the cases a set of curtains were arranged so that artificial light could be used entirely. On the whole, however, these lights are used at the present time to supplement sunlight in order to bring about a more normal growth of the plants.

In one greenhouse there has been installed a set of 10 reflectors and lights arranged 2 feet apart and about 3 feet from the greenhouse bench. Here again they have been employed for the most part to supplement sunlight.

Along one side of a greenhouse a series of compartments equipped with electric lights have been constructed for a study of the relation of light to disease. The compartments are built on a false bottom 8 inches from the floor. The individual compartments made of beaver board are 36 x 42 inches, the front of each compartment extending to the greenhouse roof, 84 inches from the floor; and the rear walls and partitions, which are 55 inches high, extend to the eaves of the greenhouse. This allows for the circulation of air between the compartments above the partitions. The front of each compartment is fitted with a heavy curtain running in grooves. The curtains and walls were painted with several coats of white enamel, while the roof and the glass sides of the greenhouse were painted to cut off the light from the outside.

A series of bowl reflectors of various sizes with lamps of different candle power were installed in the center of each compartment. They were so hung that the lower edge of the reflectors was 3 inches below the top of the partitions. At the present time lamps of 50, 100, 200, 300, 500, 750, and 1000 watts are being used.

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With the false bottom and the open space at the top together with a system of electric fans, enough circulation of air is obtained in each compartment to take care of the heat produced by the lamps so that the temperature variation is not over 2° to 3° C.

COMBINATION OF SOIL AND AIR FACTORS

The air temperature cases and the soil temperature tanks previously described can be combined in order to control various combinations of air and soil temperatures. When different soil and air temperatures are desired with the same set of plants, the air temperature cases are placed directly over the soil temperature tanks and they are each controlled in the same way as when used individually (plate 2). When the same soil and air temperature is desired, the cases and tanks are again combined. The water is drained from the tanks, the cover is removed, and the cans are placed on a stand at the same level as before. The heaters are removed from the sides of the air temperature cases and placed at the bottom of the tank, and the thermostat is lowered to a point just above the containers.

With the electric light equipment previously described, the same or different amounts of light can be used for the various cases. The same or different soil moistures can be maintained in the various cases or in the different cans in the same cases. By the use of humidostats the same or different relative humidities could be maintained in the various cases. Thus all combinations of temperatures, light, and moisture may be obtained as desired with this equipment.

INCUBATION CHAMBERS

For plants.— In studying the relation of environment to disease it is important to determine the temperatures suitable for initial infection and the period of incubation with plants of various ages, but especially with seedlings. To accomplish this, incubation chambers in which a saturated atmosphere can be maintained and in which the temperature can be held constant are necessary. The incubation chambers used were soil temperature tanks with the lid and containers removed. A stand made of laths placed one-half inch apart was placed in the tank and the water surface kept one-fourth to one-half inch below it. By means of the automatic equipment described for the control of soil temperatures the water can be kept at the temperature desired. Over the top of the tank was placed

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a glass sash, and a layer of felt was used to make a close union with the tank. Owing to the large volume of water present, these modified tanks serve most admirably for incubation chambers for seedling plants. A large population at a uniform temperature can be obtained and a heavy film of water is produced on the plants.

When temperatures below 20° C. are desired, these chambers are placed in the low temperature room.

For cultures.— It is often necessary that the growth-temperature relations of the causal organism be determined as one phase of the study of the relation of environment to diseases. For this purpose a series of incubators with a range of temperatures from near 0° to 35° C. is necessary. In obtaining a series of low temperature incubators for cultural work the same principle as that described in the low temperature greenhouse was employed.

Accordingly 4 two-door iceboxes (14x22x36 inches, inside measurements) were obtained, the ice compartment dismantled and two extra shelves put in each box so that the working capacity of the boxes was doubled. These boxes were equipped with heaters made as follows: Twenty feet of chromel wire (No. 24) was wound on each of two strips of transit connected in series and fastened to the underside of a large (12x19 inches) transit plate having a row of holes in the center the length of the plate. The whole was then set up from the floor of the boxes (2½ inches) by means of porcelain insulators.

A Chicago Surgical and Electric Co. thermostat was connected up in parallel with the heaters. The thermostats were fastened in the center of the back wall of the boxes. Pilot lights were inserted in the line between the heaters and thermostat (plate 3).

The incubators were installed in a cold storage room which was maintained at a temperature of about 4° C. The thermostats in the incubators were so set that temperatures of 5°, 10°, 15° and 20° were maintained in their respective incubators. These incubators hold as constant a temperature as that obtained with the same type of thermostats in the laboratory and have been found very satisfactory. For temperatures above 20 °, ordinary bacteriological incubators with the same type of thermostat are used in the laboratory.

The equipment herein described has been satisfactorily employed in the study of various plant disease problems, and its application to specific studies has already been published in the following articles:

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Peltier G. L.

A Study of the Environmental Conditions Influencing the Development of Stem Rust in the Absence of an Alternate Host.

I. The Viability of the Urediniospores of *Puccinia graminis tritici* Form III. Neb. Agr. Sta. Res. Bul. 22, pp. 1-15, 3 figs., September, 1922.

II. Infection Studies with *Puccinia graminis tritici* Form III and Form IX. Neb. Agr. Sta. Res. Bul. 25, pp. 1-52, 12 pls. December, 1923.

Goss, R. W.

Relation of Environment and other Factors to Potato Wilt Caused by *Fusarium oxysporum*. Neb. Agr. Exp. Sta. Res. Bul. 23, pp. 1-84, 8 figs., March 1923.

Effect of Environment on Potato Degeneration Diseases. Neb. Agr. Exp. Sta. Res. Bul. 26, pp. 1-40, 3 figs., March 1924.

Potato Wilt and Stem-end Rot Caused by *Fusarium eumartii*. Neb. Agr. Sta. Res. Bul. 27 (in press).

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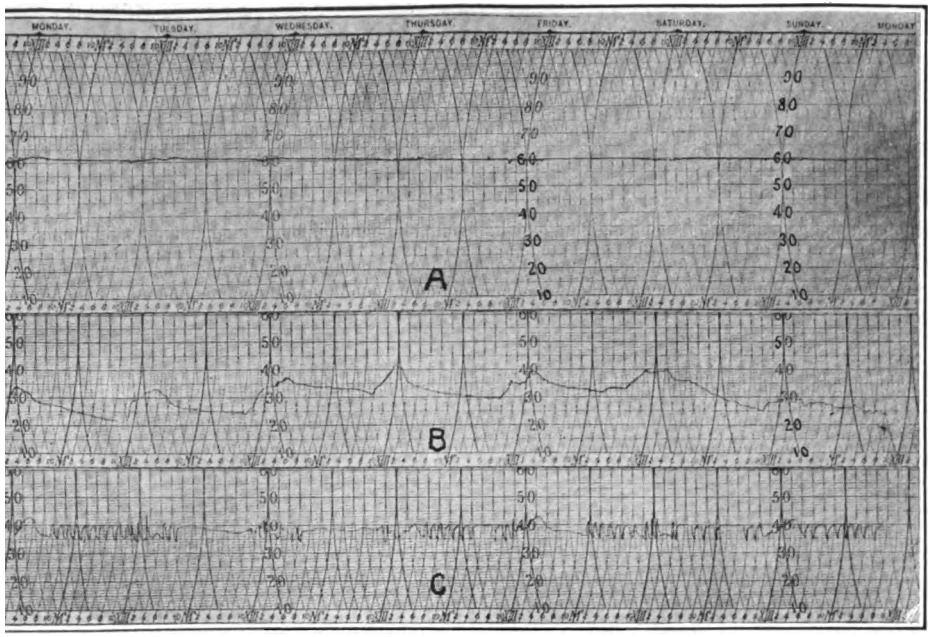

TYPICAL TEMPERATURE CHARTS

A. Of temperature case in low temperature room (same control can be obtained with either automatic or hand regulation as shown below).

B. Of low temperature room in greenhouse using hand regulation and ventilation when outside temperature is 0° C. or below.

C. Of low temperature room in greenhouse with thermostatic control of fan, (thermograph placed on top of cases at point where highest temperatures of the room are recorded).

PLATE 1

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PLATE 2

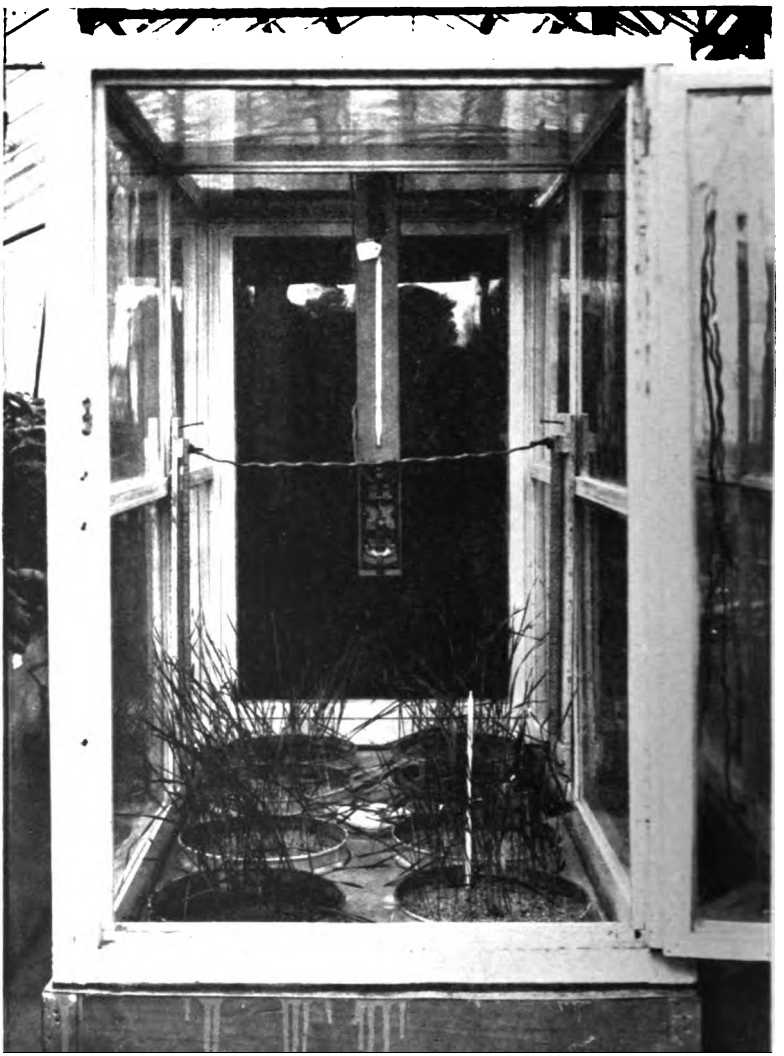

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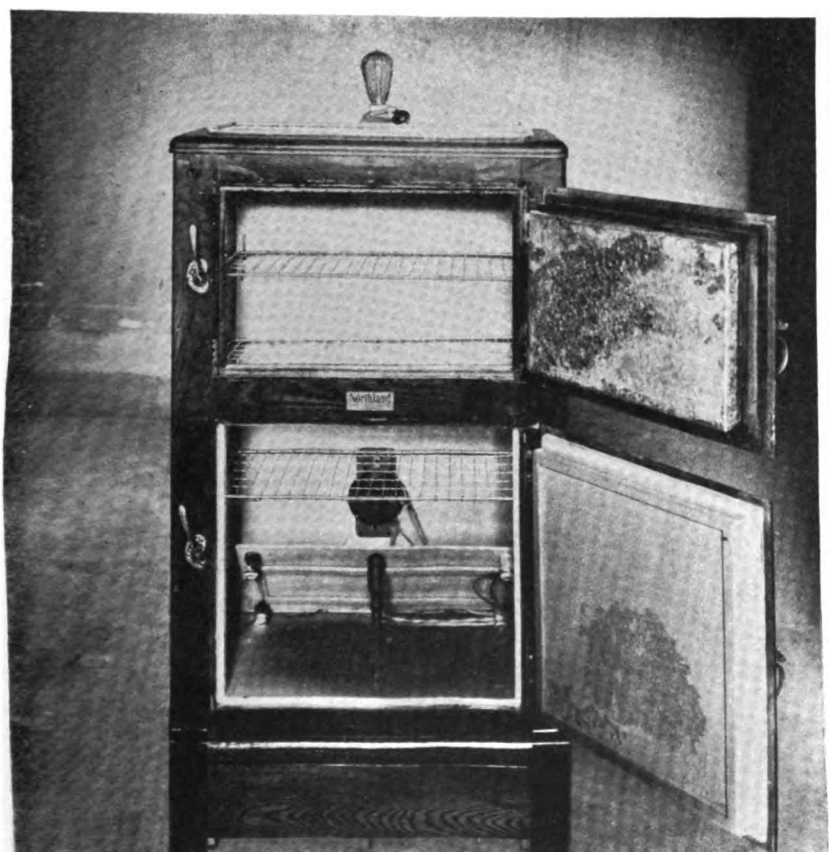
PLATE 3



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COLLEGE OF AGRICULTURE UNIVERSITY OF NEBRASKA
AGRICULTURAL EXPERIMENT STATION
RESEARCH BULLETIN 29

Further Studies on the Effect of Environment on Potato Degeneration Diseases

R. W. GOSS
and
GEORGE L. PELTIER
DEPARTMENT OF PLANT PATHOLOGY

LINCOLN, NEBRASKA
JANUARY, 1925

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SUMMARY

1. The experimental results clearly show that of the environmental factors studied, light, soil moisture, and soil temperature have very little or no effect upon the foliage symptoms of any of the degeneration diseases studied in this investigation.

2. High soil moistures and high soil temperatures appear to increase the severity of the tuber symptoms of the spindle-tuber disease. However, high soil temperatures also have a tendency to change the shape and color of the tubers of plants not affected with spindle-tuber.

3. The effects of air temperature on the foliage symptoms of the degeneration diseases have again been found to be very pronounced and it appears to be the most important factor studied in the inhibition or masking of the foliage symptoms.

4. In addition to the masking of mottling, wrinkling, ruffling, rugosity, curling, rolling, and brittleness in mosaic plants, it was found that spotting, streaking, burning, and leaf-dropping on Bliss Triumph plants affected with rugose mosaic were eliminated at a temperature of 25° C.

5. The symptoms of the various mosaic diseases on the Green Mountain variety were more pronounced than on Bliss Triumph and the masking effect at high temperatures was not as great. However, the symptoms of each disease studied were in general the same as those occurring on the Bliss Triumph variety.

6. Masking of symptoms was greatest at high temperatures with mild mosaic, while spindle-tuber symptoms were masked at low temperatures.

7. When mosaic and spindle-tuber occurred on the same plant, the severity of the mosaic symptoms decreased, while those of spindle-tuber increased, at high temperatures.

8. As a rule the masking of symptoms was not as marked at high temperatures with combinations of degeneration diseases as with a single mosaic.

9. The several and distinct diseases described by Schultz and Folsom were found to come true to type by tuber perpetuation when the possibility of infection with other diseases the previous year had been eliminated. The addition of new disease symptoms occurred

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when the plants were grown in the field subject to infection by insect transmission.

10. The splitting up of combinations of diseases in different tubers from the same plant and also in different eyes of the same tuber was noted.

11. Yellow dwarf appeared as a disease distinct from the others studied. The temperature effect was the reverse of that occurring with mosaic. At 25° the disease was very severe, while at 15° C. no symptoms appeared.

12. The application of these results to field and experimental work with these diseases is discussed.

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Further Studies on the Effect of Environment on Potato Degeneration Diseases

R. W. GOSS AND GEORGE L. PELTIER
DEPARTMENT OF PLANT PATHOLOGY

INTRODUCTION

The identification of potato degeneration diseases in the field is extremely difficult owing to the number of diseases now described, their manifestation on different varieties, the combination of several diseases on the same plant, and the further splitting up of these combinations into separate diseases. The influence of environmental factors in intensifying or inhibiting the symptoms of these diseases also increases the difficulty of diagnosis.

Additional data on the effect of environment on the symptoms of these various diseases would be of considerable value. The practical application of such data in the work of seed selection and in the extensive seed certification work now being carried on in the United States is obvious. Such data would also be of great value in the proper interpretation of the results of inoculation and field transmission studies of these diseases. One of the authors, Goss (3), has recently shown the effect of certain environmental factors, chiefly temperature, on the masking of mosaic symptoms. The application of these results to the seed certification work has been found of value but the necessity for the investigation of the effect of other factors on the symptoms of these diseases is evident.

In the present investigation the effect of environmental factors has been studied with the purpose of determining the limiting factor or factors in the masking of the symptoms, in the hopes of simplifying a complex problem by the elimination of certain other factors which have often been cited as causing a masking.

The tendency of many investigators has been to group the mosaic diseases of various host plants under one general heading on the basis of cross-inoculations. This attitude is directly contrary to that of many other potato disease investigators, who have differentiated potato mosaic into a number of separate and distinct diseases. While no inoculation

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studies have been made in the present investigation, the variety of the disease material used with the available history of the seed has allowed for a study regarding the permanence of these disease types which was thought well worth including. Accordingly, data are presented regarding the splitting up of combinations of these diseases and their varietal manifestation which is not strictly a study of environment, but which may serve to emphasize previously published work of other investigators and may be of some aid in the solution of other problems regarding these diseases.

EXPERIMENTAL METHODS

In the following work, enough soil (3 parts sod soil to 2 parts sand) was mixed at one time for all experiments. The soil moisture equivalent[1] was determined to be 15 per cent (dry weight). About 10 kilograms of soil were placed in 3-gallon earthenware jars or galvanized containers and the moisture content was then adjusted to the desired point and kept approximately constant by methods previously described (5).

Two greenhouses kept approximately at temperatures of 15° and 25° C. were used for several experiments. Repeated fumigations were made and no insects known to be invectors were observed during the experiments. In other experiments, more accurate control of temperature was obtained by the use of "temperature cases," "soil temperature tanks," and artificial refrigeration. A detailed description of all control apparatus mentioned in this bulletin has previously been published by the authors (5).

In order to minimize the experimental error, the plants to be studied under different environmental conditions were all grown from seed pieces from the same mother tuber. When this was impossible owing to the small size of the tuber or the number of conditions under which the plants were to be grown, tubers from the same hill of the previous year were used.

Detailed notes on all the seed tubers were made as to size,

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with healthy control plants growing under the same conditions. The number, weight, and appearance of all tubers produced were recorded at the end of the experiment.

The data presented on the following pages were compiled by using the average symptoms of typical plants of each disease. Owing to lack of space it is impossible to record the average symptoms of all plants grown or all the observations made on each plant. The examples here used are considered to be representative of all the plants in the experiments.

In addition to the detailed records previously mentioned, photographic records were obtained of all seed tubers, and in many cases of the plant or of typical leaves, and also of representative tubers produced. The tuber photographs allowed for careful comparison of the seed tuber with its progeny. The numerous plant and leaf photographs taken at different stages of growth were found to be of great aid in the final interpretation of the data, and served as a check on the tabulated observations of the symptoms.

SOURCE OF SEED

With a few exceptions all of the seed tubers used in these experiments were obtained thru the courtesy of Dr. Donald Folsom of the Maine Agricultural Experiment Station. Some of the seed tubers were obtained in the fall of 1923 and had been grown in Maine that year. The remainder were grown in Nebraska in 1923 from seed obtained from Maine in 1922.

Bliss Triumph units listed as Me. 1 to 40 were obtained from Maine in the fall of 1923. This lot of seed was listed by Dr. Folsom as containing the following diseases: leaf roll, mild mosaic, leaf rolling mosaic, spindle-tuber, and mild mosaic + spindle-tuber. One-half of each of the tubers was grown by Dr. Folsom in Maine and the other half used in the following experiments. In every case the diagnosis of the disease present in the half tuber grown in Maine was the same as for the half grown in the greenhouse in Nebraska. This served as a further check on the purity of the disease types used in these experiments.

Bliss Triumph units listed as Neb. 4, A to G were from seed obtained from Maine in 1922 and grown in the field in western Nebraska in 1923. No precautions were taken to pre-

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presented in this paper except in a few cases where notations of the differences occurring are presented. The various units of the original seed obtained from Maine were listed as containing the following diseases: mild mosaic, medium plus mosaic which appeared to be a combination of spindle-tuber + rugose mosaic, spindle-tuber, spindle-tuber + mild mosaic, and curly dwarf which appeared to be a combination of spindle-tuber + leaf-rolling mosaic.

Green Mountain tubers listed on page 22 were obtained from Maine in the fall of 1923. These tubers were produced in the field and were subject to infection with other diseases thru uncontrolled insect transmission. These tubers were listed as containing leaf roll, leaf rolling mosaic, mild mosaic, rugose mosaic, and spindle-tuber. The plants grown from these tubers showed that considerable infection, chiefly with rugose mosaic, had occurred the previous year, as noted on page 23.

Samples of tubers affected with yellow dwarf were obtained thru the courtesy of Mr. L. M. Fenner of Cornell University. One lot of tubers of the White Rose variety and another lot of the Early Rose variety, both of which had been grown in the field in New York in 1923, were used in these tests.

Control plants for all experiments with the Bliss Triumph variety were grown from healthy seed obtained from plants selected in certified fields the previous summer and no mosaic appeared in any of the controls. Healthy Green Mountain tubers were obtained from Dr. Folsom.

RELATION OF LIGHT TO DISEASE SYMPTOMS

An attempt was made to determine the possible effect of different intensities of artificial light on the disease symptoms. Seed affected with the following diseases was used in the experiment: spindle-tuber + mild mosaic, medium plus mosaic, curly dwarf, mild mosaic, leaf-rolling mosaic, and rugose mosaic. Healthy seed was used as controls. Plants grown under different light intensities were either from the same seed tuber or the tubers were from the same hill. The soil moisture content was kept at 1¼ M. E. and all plants were grown at a temperature of 15°–18° C. Detailed notes were made when the plants were 10–15 cm. high and every two weeks thereafter.

The light chambers previously described (5) were employed. Mazda lights of 50, 100, 200, 300, 500, 750, and 1000

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watts were used. These lights were on continuously thruout the experiment. Another set of plants were grown in the same greenhouse in sunlight.

Observations of the disease symptoms were difficult, owing to the type of growth occurring under the conditions of the experiment. The plants in all the light chambers showed considerable lengthening of the internodes and the leaves were much reduced in size. At the lowest light intensities there also occurred a great deal of chlorosis and some leaf-dropping on both healthy and diseased plants.

Results:—No effect of the different degrees of light intensities on the symptoms of the various diseases was evident at any time during the experiment. The symptoms of each disease appeared the same as those recorded for other plants grown at the same temperature in sunlight, (p. 15), and need not be presented here.

It was therefore evident that a decrease in the intensity of light from that normally occurring in the greenhouse, even with increased duration (continuous light), had no effect on the symptoms of the diseases studied. It was unfortunate that lights of much greater intensity than those used in this experiment were not available as it is very possible that an increase in the light intensity would have had a very considerable effect on the foliage symptoms, particularly on mottling.

Schultz and Folsom (6) note that a "reduction in sunlight decreased apparent dwarfing, and increased mottling," in experiments with various types of potato mosaic. The masking of mosaic symptoms, particularly mottling, has been noted by several writers in the high-altitude, dry-land sections of the west. This phenomenon is of common occurrence in western Nebraska. The intense sunlight prevailing at this high altitude, probably about 10,000 foot candles on clear days, may possibly affect the degree of mottling. In the experiments reported above, the greatest light intensity used, as obtained from a 1000-watt light, produced approximately 450 foot candles. Even tho the light was used continuously, the total amount of light received by the plants would be much less than that occurring in western Nebraska on a clear day. Field observations, however, are subject to considerable error because of the presence of other uncontrolled factors. Increase in sunlight is usually associated with increase in temperature, which may be the limiting factor involved. Further studies should be made under controlled conditions using greater light intensities than those here employed.

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RELATION OF SOIL MOISTURE TO DISEASE SYMPTOMS

The following experiment was planned to determine what effect, if any, the moisture content of the soil has upon the symptoms of the various degeneration diseases.

Methods:—All plants were grown in 3-gallon earthenware jars containing about 10 kilograms of soil. The moisture content and the moisture equivalent of the soil were determined before planting and the moisture content was then adjusted to the desired points and kept approximately constant by methods previously described (5). A total of 136 jars were used. These were divided into 2 sets, and placed in greenhouses maintained at approximate temperatures of 15° and 25° C. Each set was divided into 4 lots, having different soil moisture contents. The soil moisture contents were held at 2/3, 1, 1¼, and 1½ of the moisture equivalent.

Bliss Triumph seed tubers from practically all the disease lots listed on page 7 were used. Some of the seed tubers were divided into 4 pieces and grown at the 4 different moisture contents at the same temperature. Others were divided and grown at different temperatures but with the same moisture content. Thus all comparative tests with each disease were made as far as possible with seed from the same mother tuber, or at least from the same hill of the preceding year.

Observations were made on each plant every 2 weeks after the plants were 10 to 15 cm. high until the death of the plant. Detailed notes were made of the presence and severity of all symptoms and additional notes taken as necessary; these were supplemented by photographic records in many instances.

Results:—No correlation could be made at any time during the experiment between the symptoms of the various diseases and the moisture content of the soil. There was a tendency for slightly increased ruffling, rolling, uprightness, and rigidity at the higher moisture contents but the same tendency was manifest in the control plants, and the changes in these symptoms were very slight. The curly dwarf plants grown at 25° C. appeared to have slightly more severe symptoms at a moisture content of 1¼ M.E. than at the lower and higher moisture contents; but as the plants at this moisture content were from a different hill than the others, no conclusions could be drawn. With the medium plus mosaic plants there was a slight increase in the severity of spotting, streaking, burning, and leaf-dropping with increasing moisture contents, but the increase was very slight. The plants affected with spindle-tuber sometimes showed a tendency to produce

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TABLE 1—*Relation of soil moisture to disease symptoms*

Mild Mosaic

seed	Plant No.	Soil moisture content[2]	Symptoms[1]															
			Dwarfing	Chlorosis	Mottling	Wrinkling	Ruffling	Rugosity	Curling	Rolling	Uprightness	Rigidity	Brittleness	Spotting	Streaking	Burning	Leaf-dropping	Early death
		M. E.																
–4	66	2/3	2	..	3	2	2	..	..	..	..	..	..	..	..	..	..	..
–4	67	1	2	..	3	2	2	..	..	..	..	..	..	..	..	..	..	..
–5	69	1¼	1	..	3	2	2	..	..	..	..	..	..	..	..	..	..	..
–5	71	1½	1	..	3	2	3	..	..	..	..	..	..	..	..	..	..	..

severity of the symptoms is graded numerically as follows: 1 = slight, 2 = medium, and 3 = severe; 0 or the absence of any symbol mptom did not appear.
l on soil moisture equivalent.

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tubers with more severe symptoms at the higher moisture contents but these results were not consistent.

Table 1, compiled from the notes taken on typical mild mosaic plants grown at 15° C., shows no change in the symptoms at the different moisture contents. This is typical of the other plants in the experiment. Plate 1 shows the absence of any effect of the soil moisture content on the control plants and on spindle-tuber plants.

Discussion:—While several workers have observed that during dry seasons the symptoms of mosaic were masked, the results of this experiment do not show any evidence to support these observations, at least as regards soil moisture. It is possible that atmospheric moisture might be a factor in changing the symptoms, but the observations of the authors on plants grown in different greenhouses often having different relative humidities have not indicated that this would occur, so that no experimental studies have been attempted.

It has been pointed out in a previous paper (3) that changes in the symptoms of these diseases during wet weather can often be correlated with decreased temperature, which is undoubtedly a greater factor than soil moisture. More extensive studies, however, are being made regarding the possible changes in the tuber symptoms of spindle-tuber plants grown at different soil moisture contents, as this disease has been reported to be particularly severe under irrigation (7).

RELATION OF SOIL TEMPERATURE TO DISEASE SYMPTOMS

While numerous workers have noted the effect of air temperature on the symptoms of potato mosaic, the authors are not aware of any experimental studies of the effect of soil temperature on the symptoms. The following experiment was therefore planned to determine whether or not different soil temperatures would have any effect on the symptoms when the air temperature was kept at an optimum point for the appearance of symptoms.

Methods:—The following diseases were studied in this experiment on the Bliss Triumph variety: mild mosaic, spindle-tuber, spindle-tuber + mosaic, curly dwarf, and medium plus mosaic. Healthy Bliss Triumphs were used as controls. Seed pieces from the same tuber or from tubers from the same hill were cut into equal sized pieces and planted at 4 different soil temperatures. The plants were grown in galvanized containers holding 10 kilograms of soil, which was held at a soil moisture content of 1¼ M.E. Immediately after

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planting, the containers were placed in soil temperature tanks held at the following temperatures: 14°, 18°, 22°, and 26° C. The air temperature was kept at approximately 15° C. thruout the experiment.

Records were made as in previous experiments.

Results:—An examination of the data presented in Table 2 will show that no change in the symptoms occurred on the foliage of plants affected with mild mosaic (Plate 2, A), spindle-tuber, or spindle-tuber + mosaic. The symptoms of mild mosaic at all temperatures were typical for the disease. The plants affected with spindle-tuber showed only a slight dwarfing and uprightness. No ruffling was observed. These symptoms of spindle-tuber are typical for all plants grown at an air temperature of 15° C. The spindle-tuber + mosaic plants were grown from seed obtained from spindle-tuber plants which had evidently acquired mosaic in the open field the previous summer.

While the soil temperature had no effect on the above-ground symptoms of all these plants, there was a very marked change in the type of tuber produced.

With high soil temperatures the elongation and paler color of the tubers produced by the plants affected with spindle-tuber were more severe (Plate 2, B). However, tubers from healthy plants and from mild mosaic plants often tend to show these same tuber characteristics at high soil temperatures (Plate 2, C). This same phenomenon regarding the change in shape and color of tubers grown at high soil temperatures has been noted by L. R. Jones, *et al.* (4) in their investigation on potato scab. This fact made it very difficult to distinguish between tubers affected with spindle-tuber grown at low temperatures and healthy or mosaic tubers grown at high temperatures. Further investigations of this temperature effect on the tuber symptoms are being undertaken.

The curly dwarf and medium plus mosaic tubers produced weak, spindling plants at all temperatures. With these two diseases, germination was greatly delayed. The plants were weaker and more spindling with very small leaves at the higher temperatures, and the leaf symptoms of mosaic were not as marked under these conditions, as shown by the medium plus mosaic plants listed in Table 2.

From this experiment we may conclude that soil temperature has no effect on the above-ground symptoms of mild mosaic and spindle-tuber. High soil temperatures tend to increase the length of the tuber and decrease the color, not only in spindle-tuber progeny but also in the progeny of

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TABLE 2—*Relation of soil temperature to disease symptoms*

Source of seed	Plant No.	Soil temperature °C.	Symptoms[1]																	
			Dwarfing	Chlorosis	Mottling	Wrinkling	Ruffling	Rugosity	Curling	Rolling	Uprightness	Rigidity	Brittleness	Spotting	Streaking	Burning	Leaf-dropping	Early death	Tuber symptoms[2]
MILD MOSAIC																				
29A	25	14	1	..	3	2	2	..	..	..	..	..	..	..	..	..	..	..	0
29B	26	18	1	..	3	2	2	..	..	..	..	..	..	..	..	..	..	..	0
29C	27	22	1	..	3	2	2	..	..	..	..	..	..	..	..	..	..	..	0
29C	28	26	1	..	3	2	2	..	..	..	..	..	..	..	..	..	..	..	2
SPINDLE-TUBER																				
40A	29	14	1	..	..	..	..	..	..	..	2	..	..	..	..	..	..	..	1
40B	30	18	1	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	1
40C	31	22	1	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	1
40D	32	26	1	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	2
SPINDLE-TUBER + MOSAIC[3]																				
Neb. 4E32—1	5	14	3	..	3	3	3	..	1	..	3	2	2	..	..	1	1	..	1
Neb. 4E32—1	6	18	2	..	3	3	3	..	1	..	3	2	2	..	..	..	1	..	3
Neb. 4E32—1	7	22	3	..	3	2	3	..	1	..	3	2	2	..	..	..	1	..	2
Neb. 4E32—1	8	26	2	..	3	2	3	..	1	..	3	2	2	..	..	1	1	..	3
MEDIUM PLUS MOSAIC (SPINDLE-TUBER + RUGOSE MOSAIC)																				
Neb. 4F15—1	13	14	3	..	3	3	3	..	2	..	3	2	..	..	..	1	1	..	2
Neb. 4F15—1	14	18	3	1	2	3	3	2	3	..	1	..	..	..	1	1	3	..	0[4]
Neb. 4F15—1	15	22	3	..	2	2	2	..	2	..	..	..	..	..	..	1	1	..	2
Neb. 4F15—1	16	26	3	..	1	1	1	..	1	..	..	..	..	..	..	..	..	..	3[5]

[1]See Table 1.
[2]Tuber symptoms refer to tubers showing symptoms of the spindle-tuber disease.
[3]Leaf-dropping was accompanied by corrugations on stem. See footnote p. 19.
[4]No tubers produced.
[5]Leaves and plant very small and weak.

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healthy and mosaic plants. With plants affected with a combination of diseases, such as those listed, as curly dwarf and medium plus mosaic, high soil temperature results in such a weak spindling plant that the leaf symptoms are often not observable.

RELATION OF AIR TEMPERATURE TO DISEASE SYMPTOMS

EXPERIMENT IN GREENHOUSE

In the soil moisture experiments previously described, an excellent opportunity was afforded to study the effect of temperature on the symptoms of these diseases. This experiment was run in duplicate in two greenhouses held at temperatures of 15° and 25° C. At the time of the second reading, that is, two weeks after the plants were 10–15 cm. high, some of the plants in the 15° house were changed to the 25° greenhouse and *vice versa*. It was thus possible to observe not only the typical symptoms which appeared at 15° and 25°, but also the changes in the symptoms when plants were changed from one temperature to the other. This allowed for a checking up on the work previously published by one of the authors (3) and also for the further study of diseases of which seed was not available when the previous work was undertaken.

The methods used in this experiment have already been discussed on p. 10.

Results:—The data presented in Table 3 are from a few typical examples of the plants used in this experiment. Space will not permit the tabulation of all the data collected during the experiment. The results of this experiment in general corroborated the conclusions presented in the previous publication (3). The large number of plants used, the greater number of diseases, and the better growing conditions allowed for more detailed notes on the changes in symptoms than was possible in the earlier experiments.

Mottling was again found to be the most constant symptom of mosaic at all temperatures, altho a change in the type and degree of mottling was clearly evident. At 15° C. all

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TABLE 3—*Relation of air temperature to disease symptoms*

Source of seed	Plant No.	Air temperature °C.	Foliage	Symptoms[1]																	
				Dwarfing	Chlorosis	Mottling	Wrinkling	Ruffling	Rugosity	Curling	Rolling	Uprightness	Rigidity	Brittleness	Spotting	Streaking	Burning	Leaf-dropping	Early death	Tuber symptoms[3]
MILD MOSAIC																				
Me. 28B	104	15	all	1	..	3	2	2	..	..	..	..	..	..	..	..	..	..	..	0
Me. 28B	103	15	all	..	..	3	2	2	..	..	..	..	..	..	..	..	..	..	..	
Me. 28B	103	25	old	..	..	1	1	1	..	..	..	..	..	..	..	..	..	..	..	
Me. 28B	103	25	new	..	..	1[d2]	0	1	..	..	..	..	..	..	..	..	..	..	..	0
Me. 28D	108	25	all	..	..	0	0	1	..	..	..	..	..	..	..	..	..	..	..	0
Me. 28D	107	25	all	..	..	1[d]	0	1	..	..	..	..	..	..	..	..	..	..	..	
Me. 28D	107	15	old	..	..	1	0	1	..	..	..	..	..	..	..	..	..	..	..	
Me. 28D	107	15	new	..	..	3	2	2	..	..	..	..	..	..	..	..	..	..	..	0
Neb. 4B5—4	67	15	all	2	..	3	2	2	..	..	..	..	..	..	..	..	..	..	..	0
Neb. 4B5—4	68[3]	15	all	..	..	3	3	2	..	..	..	..	..	..	..	..	..	..	..	
Neb. 4B5—4	68	25	old	..	..	3	3	2	..	..	..	..	..	..	..	..	..	..	..	
Neb. 4B5—4	68	25	new	..	..	0	0	0	..	..	..	..	..	..	..	..	..	..	..	0
Neb. 4B5—7	75	25	all	1	..	1[d]	1	1	..	..	..	..	..	..	..	..	..	..	..	0
MEDIUM PLUS MOSAIC (SPINDLE-TUBER + RUGOSE MOSAIC)																				
Neb. 4B18—2	51	15	all	2	..	3	3	2	1	2	..	2	..	..	1	..	1	1	..	0
Neb. 4B18—2	52	15	all	..	..	2	3	2	1	2	..	2	..	..	1	..	..	1	..	
Neb. 4B18—2	52	25	old	..	..	2[d]	2	1	0	0	..	2	..	..	1	..	..	1	..	
Neb. 4B18—2	52	25	new	..	..	1[d]	1	1	0	0	..	2	..	..	0	..	..	0	..	0

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3 (Continued)—*Relation of air temperature to disease symptoms*

	Foliage	Symptoms[1]																	Tuber symptoms[4]
		Dwarfing	Chlorosis	Mottling	Wrinkling	Ruffling	Rugosity	Curling	Rolling	Uprightness	Rigidity	Brittleness	Spotting	Streaking	Burning	Leaf-dropping	Early death		
MEDIUM PLUS MOSAIC (SPINDLE-TUBER + RUGOSE MOSAIC)—Continued																			
5	all	..	..	2[d]	1	1	1	..	..	1	..	..	..	..	..	..	..		3
5	all	..	..	1[d]	1	2	0	0	..	1	..	..	..	0	0	0	..		
5	old	..	..	1	2	2	1	0	..	2	..	..	..	0	0	2	..		
5	new	..	..	3	3	3	3	2	..	2	..	..	..	1	1	2	..		0
CURLY DWARF																			
5	all	3	..	2	2	2	1	..	3	2	2	1	..	..	..	..	..		1
5	all	3	..	2	2	1	1	..	3	2	2	2	..	..	..	..	..		
5	old	..	..	1	2	1	0	..	1	3	0	0	..	..	..	..	..		
5	new	..	..	2[d]	0	1	0	..	0	3	0	0	..	..	..	..	..		1
SPINDLE-TUBER																			
5	all	1	..	..	..	1	..	..	..	1	..	..	..	..	..	..	..		1
5	all	..	..	..	..	0	..	..	..	0	..	..	..	..	..	..	..		
5	old	..	..	..	..	1	..	..	..	0	..	..	..	..	..	..	..		
5	new	..	..	..	..	1	..	..	..	2	..	..	..	..	..	..	..		3
5	all	1	..	..	..	1	..	..	..	2	..	..	..	..	..	..	..		2
5	all	..	..	..	..	1	..	..	..	2	..	..	..	..	..	..	..		
5	old	..	..	..	..	1	..	..	..	2	..	..	..	..	..	..	..		
5	new	..	..	..	..	0	..	..	..	1	..	..	..	..	..	..	..		1

[2]d = diffuse mottling. [3]See Plate 3A. [4]See Plate 3B. [4]See Table 2, footnote 2.

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slight mottling of this diffuse type that would easily be missed in a casual observation. Occasionally no mottling at all could be detected on the new leaves. Plants with mild mosaic and mild mosaic combined with spindle-tuber when grown at 25° often did not show any symptoms when they were small but when changed to a low temperature the old leaves showed slight mosaic symptoms and the new leaves were severely mottled, wrinkled, and ruffled, (Plate 4, U25-L25).

It is thus evident that the masking of mottling at high temperatures is chiefly a change in the type and degree of mottling on the old leaves, sometimes accompanied by an entire absence of mottling on the new leaves. The complete elimination of mottling at high temperatures on leaves previously showing this symptom at low temperatures has never been observed in our greenhouse experiments. It is entirely possible that mottling could be eliminated on old leaves by growing the plants at a temperature high enough to mask the mottling, changing them to a low temperature for a sufficient period to bring out the first signs of mottling and then immediately transferring them back to the high temperature. In fact, this phenomenon has often been observed in the field and has previously been recorded (3). Possibly intense sunlight during this period of high temperature assists in the change. This supplementary factor, of course, did not come into play in the greenhouse experiments. It is clearly evident that mottling becomes "fixed" with the increasing age of the foliage having this symptom.

Wrinkling and ruffling, the other two characteristic symptoms of mild mosaic, tended to disappear entirely at a high temperature; the masking of these symptoms was more complete than that occurring with mottling. The same was true of rugosity, curling, rolling, and brittleness when these symptoms occurred on mosaic plants. The change in the rolling symptoms was particularly noticeable in the "curly dwarf" plants changed from a low to a high temperature (Plate 3, B). Just what combination of diseases occurred in these plants is questionable; the symptoms differed from any of the others studied in this experiment.

In addition to the temperature effects on the above symptoms, changes were also noted in other symptoms not previously reported. In two units (medium plus mosaic) presented in Table 3 there was evidently present rugose mosaic with spindle-tuber. These plants and other rugose mosaic plants were badly affected with streaking, spotting, burning,

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stem corrugations,[1] and leaf-dropping when grown at low temperatures. These symptoms, at least in the Bliss Triumph units, did not appear on plants grown at 25° C. As soon as the plants were transferred to 15°, however, these symptoms appeared and the reverse was true of plants started at 15° and changed to 25°.

While all the symptoms of mosaic tend toward masking with increase in temperature as stated above, the exact opposite condition holds true for spindle-tuber and for some of the spindle-tuber symptoms when in combination with mosaic. The general uprightness of the plants and the erect appearance of the branches and leaves, which is one of the most evident symptoms of spindle-tuber, is greatly increased by high temperature. Spindle-tuber plants grown at 15° C. were hardly discernible from the healthy controls (Plate 1), but when changed to 25° the general character of the plant growth was markedly different. The ruffling symptom of the leaves of spindle-tuber plants sometimes shows an increase with a rise in temperature but this did not occur on all plants. In general the leaves of plants affected with spindle-tuber when grown at 25° show a slight downward rolling of the leaves, and the leaves are longer, narrower, smoother and more pointed than on a healthy plant. The elongation and the paler color of the tubers when spindle-tuber plants are grown at high temperature has already been referred to and occurred again in this experiment.

The leaf roll plants used in this experiment were not changed from 15° to 25° C. until 8 weeks after emergence. The only change in the symptoms was a general chlorosis and earlier death at the higher temperature. It is possible that the rolling of the leaves would have been influenced by the high temperature if the plants had been changed at an earlier date.

EXPERIMENT IN AIR TEMPERATURE CONTROL CASES

In this experiment a more accurate control of air temperature was possible than in the experiment in the open greenhouse previously discussed. While the number of plants was smaller, the use of 4 different air temperatures accurately controlled allowed for a careful checking up of the previous experiments.

[1] "Stem corrugations" refer to peculiar necrotic areas on the stem just below the leaves. These areas are made up of parallel horizontal cracks, brown in color, extending ¼ to ½ around the stem for a distance of 1 to 2 inches below the leaf axil. These corrugations were associated with the leaf-dropping occurring with rugose mosaic.

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TABLE 4—*Relation of air temperature to disease symptoms*

Source of seed	Plant No.	Air temperature °C.	Symptoms[1]															
			Dwarfing	Chlorosis	Mottling	Wrinkling	Ruffling	Rugosity	Curling	Rolling	Uprightness	Rigidity	Brittleness	Spotting	Streaking	Burning	Leaf-dropping
MILD MOSAIC																		
Neb. 4G11—1	17	14	..	..	3	2	2	..	..	..	..	..	..	..	..	..	..	
Neb. 4G11—1	18	18	..	..	2	1	1	..	..	..	..	..	..	..	..	..	..	
Neb. 4G11—1	19	22	..	..	1[d][2]	1	1	..	..	..	..	..	..	..	..	..	..	
Neb. 4G11—1	20	26	..	..	0	0	0	..	..	..	..	..	..	..	..	..	..	
SPINDLE-TUBER																		
Neb. 4B26—2	5	14	0	..	..	..	1	..	..	..	0	..	..	..	..	..	..	
Neb. 4B26—2	6	18	0	..	..	..	1	..	..	..	0	..	..	..	..	..	..	
Neb. 4B26—1	7	22	1	..	..	..	2	..	..	..	1	..	..	..	..	..	..	
Neb. 4B26—1	8	26	1	..	..	..	2	..	..	..	3	..	..	..	..	..	..	
SPINDLE-TUBER + MILD MOSAIC																		
Neb. 4B23—1	9	14	0	..	3	2	2	..	..	..	0	..	..	..	..	..	..	
Neb. 4B23—1	10[3]	18	1	..	2	1	1	..	..	..	1	..	..	..	..	..	..	
Neb. 4B23—2	11	22	1	..	2[d]	1	1	..	..	..	3	..	..	..	..	..	..	
Neb. 4B23—2	12	26	1	..	0	0	2	..	..	..	3	..	..	..	..	..	..	
MEDIUM PLUS MOSAIC (SPINDLE-TUBER + RUGOSE MOSAIC)																		
Neb. 4G17—1	13	14	0	..	2	3	3	3	3	..	0	..	..	1	1	..	1	
Neb. 4G17—1	14	18	1	..	2	2	2	2	1	..	1	..	..	0	0	..	1	
Neb. 4G17—1	15	22	1	..	1[d]	2	2	1	0	..	1	..	..	0	0	..	1	
Neb. 4G17—1	16	26	1	..	0	1	1	1	0	..	2	..	..	0	0	..	1	

[1]See Table 1. [2]*d* = diffuse mottling. [3]See Plate 4A.

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Methods:—The temperatures used were 14°, 18°, 22°, and 26° C. These temperatures were obtained by electrically heated and controlled chambers placed in the refrigeration compartment of the greenhouse as described previously (5). The plants were grown in containers similar to those used in the soil temperature experiment and the soil moisture was held at the same point.

Five diseased and one control plant were grown at each temperature. When possible, all 4 plants were grown from the same mother tuber. In some instances, however, the small size of the seed made it necessary to use two tubers, in which case they were always taken from the same hill. Detailed readings were made every two weeks after emergence. At the end of the third reading some of the plants had reached the top of the cases, so that the experiment was discontinued.

During the course of the experiment, sunlight was supplemented during the short days of winter and on cloudy days by artificial light, using 1000-watt nitrogen filled lamps (Mazda C) suspended over the cases in large bowl reflectors.

Results:—A summary of the symptoms appearing on the individual plants is given in Table 4. With the mosaic plants all the symptoms were more pronounced and distinct at 14° C. than at the higher temperatures. At 26° practically all the symptoms were very indistinct or absent. With mild mosaic plants, mottling was severe at 14° C., moderate but distinct at 18°, slight and diffused at 22°, while at 26° mottling was entirely absent. Along with mottling, the symptoms of wrinkling and ruffling tended to gradually disappear as the temperature was increased.

The only two symptoms present on the spindle-tuber plants were ruffling and uprightness, both of which increased in distinctness and severity with increased temperatures. In other words, it is quite apparent that whereas the mild mosaic symptoms were masked by high temperatures, the reverse occurred in the case of spindle-tuber symptoms.

With a combination of spindle-tuber and mild mosaic, mottling and wrinkling reacted to temperature as in the case of mild mosaic. It has been shown that at low temperatures ruffling is very pronounced with mild mosaic plants whereas at high temperatures ruffling is intensified on spindle-tuber plants. Thus at 14° C. the pronounced ruffling of the mild mosaic disease appears, while at 18° and 22° it tends to disappear. However, at 26° C., where ruffling disappears in mild mosaic plants, it is intensified in spindle-tuber plants, so that ruffling is as pronounced at 26° with the combination of

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spindle-tuber and mild mosaic as it is at 14°, due wholly to the two types of diseases present (Plate 4, A).

Somewhat different results were obtained with medium plus mosaic (probably spindle-tuber and rugose mosaic). Uprightness increased, mottling, wrinkling, rugosity, and curling decreased, with progressively higher temperatures, while the symptoms of spotting and streaking occurred only at 14° C. A slight leaf-dropping appeared at all temperatures. The effect of the rugose mosaic in this combination, however, resulted in a decrease in ruffling at the high temperatures in contrast to the combination of spindle-tuber and mild mosaic where the reverse occurred.

No correlation between the curly dwarf plants grown at the different temperatures can be made owing to the fact that the seed pieces planted at 22° and 26° C. failed to sprout.

The 4 control plants remained free from any symptoms thruout the experiment.

RELATION OF AIR TEMPERATURE TO DISEASE SYMPTOMS WITH THE GREEN MOUNTAIN VARIETY

All of the experiments previously recorded in this paper were conducted with the Bliss Triumph variety. Inasmuch as the published experimental and descriptive data on these diseases in the United States have in a great measure been obtained with the Green Mountain variety, it was thought that parallel experiments with plants of this variety and the Bliss Triumph variety would be well worth while in checking up the effect of temperature on these symptoms and the varietal modifications of the symptoms of these diseases.

Methods:—The tubers used in this experiment were obtained thru the courtesy of Dr. Donald Folsom, who grew one-half of each tuber in Maine to check up on the previous diagnosis while the other half was used in this experiment. Each half grown in this experiment was again divided into 2 seed pieces and planted in containers holding 10 kilograms of soil held at 1¼ M.E. Duplicate plants from the same seed tubers were grown at 25° and 15° C. Detailed readings were made as in previous experiments.

Results:—Unfortunately most of the seed used in this experiment had become infected with other degeneration diseases during the previous season. A few of the plants, however, came true to type and allowed for the following observations and comparisons.

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LEAF ROLL:—Two of these plants showed the presence of mosaic, while the other two were pure leaf roll. No difference in the amount of rolling at 15° and 25° C. was observable. The rolling was more severe on the lower leaves and in no instance was it as pronounced as on the Bliss Triumph variety grown under the same conditions. Dwarfing was not as evident nor were the leaves as brittle or rigid on the Green Mountain as on the Triumphs.

LEAF-ROLLING MOSAIC:—All of these plants were affected with rugose mosaic so that no clear-cut comparisons could be made with the Bliss Triumphs. The temperature effect was the same as with all other mosaic types studied, all of the symptoms being reduced in severity at the high temperature.

MILD MOSAIC:—These units were also affected with rugose mosaic. The symptoms were not greatly masked by a temperature of 25° C., mottling being the only symptom that decreased in severity, all other symptoms remaining approximately the same at both temperatures.

RUGOSE MOSAIC:—The effect of a high temperature on the symptoms of this disease was very slight. The mottling was of the diffuse type but remained about the same at both temperatures. The other symptoms behaved likewise.

SPINDLE-TUBER:—Two of these plants were affected with rugose mosaic while the other two showed pure spindle-tuber. The ruffling of the leaves and the upright habit of the plant were much more evident at 25° than at 15° C. Both of these symptoms were much more severe than occurred in the Bliss Triumph variety (Plate 5).

Discussion:—While a relatively small number of plants (24) were grown in this experiment, certain differences were very marked and consistent. In general, it may be stated

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RELATION OF AIR TEMPERATURE AND SOIL MOISTURE TO THE SYMPTOMS OF YELLOW DWARF

In order to become acquainted with the symptoms of yellow dwarf (1), a disease which has never been reported to occur in Nebraska, and to study it in comparison with other types of degeneration diseases, a few tubers of infected Early Rose and White Rose potatoes were obtained thru the courtesy of Mr. L. M. Fenner of the Department of Plant Pathology, Cornell University.

All of these tubers showed varying amounts of cracking, internal necrosis, and stem-end rot as well as other tuber symptoms somewhat similar to those of spindle-tuber. In fact, at first glance many of the tubers had the appearance of being affected with both spindle-tuber and *Fusarium eumartii* Carp. Cultures from such tubers, however, were always sterile, and the necrotic tissues in the tuber as well as the later appearance of wilt in the plant were markedly different from those occurring with *F. eumartii* or any other disease with which the authors were familiar.

The tubers were divided into halves and grown at temperatures of 15° and 25° C. In addition, half of the plants at each temperature were grown in a very dry soil while the others were grown at a high soil moisture content.

Results:—The differences in the plants grown at different temperatures were very marked thruout the entire experiment (Plate 6). Practically no differences were noted as being due to soil moisture. Emergence naturally occurred first with the higher moisture content and at the higher temperature. After the disease symptoms appeared, the death of the plant occurred earlier with a low soil moisture, but the individual symptoms were the same at both soil moistures.

Of the 8 plants grown at 25° C., 4 of them completely wilted early in the experiment. The other 4 were very severely wilted when dug. The disease was evidenced in every case by the plants being dwarfed but with thick stems, and by early chlorosis followed by the death of the terminal shoot and later of the auxiliary buds. Discoloration of the vascular system and the pith of the stems and branches was very marked. The leaves wilted completely and there was considerable leaf-dropping both of the lower and of the upper leaves.

At 15° C. none of the plants showed symptoms of disease, aside from a slight ruffling of the leaves, thruout the entire experiment.

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The symptoms on the tubers produced at the two temperatures showed as great a difference as did the foliage symptoms. Three of the plants grown at 25° C. died before any tubers were formed. The other 5 plants produced 10 small tubers, all of which showed varying degrees of cracking and internal necrosis. The 8 plants grown at 15° C. produced 26 tubers, of which 2 showed very slight internal necrosis while all the others appeared healthy.

Healthy Bliss Triumph tubers were planted in the soil in which 4 of the yellow dwarf plants had died early in the experiment. The Triumph plants produced large, healthy vines and a good crop of healthy tubers, and no evidence of the disease occurred.

While the number of plants used was rather small, the differences were more marked than with any of the other diseases studied. It was clearly evident that yellow dwarf is a high temperature disease and that it would be very hard to detect the disease at low temperatures. With high temperatures the disease is more severe in its action than any of the other degeneration diseases studied by the authors.

The symptoms of this disease are markedly different from any of those occurring with the other types of degeneration studied. Some of the symptoms of these plants, however, showed a great similarity to the spindle-tuber disease, which may have been present along with yellow dwarf. Judging from the plants used in this experiment, the authors can see no reason for believing that this disease is a combination of any of the other degeneration diseases of potatoes. The symptoms are markedly different from any type of mosaic with which the authors are familiar and the reaction of the symptoms to temperature is the exact reverse of that occurring with mosaic.

COMBINATIONS OF DEGENERATION DISEASES

In the preceding pages the symptoms of several disease units have been recorded as being a combination of two diseases on the same plant. Such combinations have been described and discussed by Schultz and Folsom (6). Some of the seed obtained from Dr. Folsom and used in the present investigation was labelled as being a combination of two diseases (see p. 7). Such seed has produced plants having symptoms corresponding to those expected with such combinations. There has sometimes occurred, however, an evident splitting up of the combination into two distinct types of disease. This

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splitting more often results in one plant showing the symptoms of a single disease while the other plant from the same unit appears as the original combination.

The authors have made no effort in the present investigation to secure accurate evidence of such combinations by inoculation methods. The evident splitting up of such combinations or the addition of new symptoms in the progeny of a plant previously showing symptoms of a single disease has been repeatedly observed, however. While these data are not directly concerned with the effect of environment on mosaic symptoms, it might be well to present typical examples in support of the data presented by Schultz and Folsom (6) and in an effort to explain some of the material presented in this paper.

Some of the units of spindle-tuber obtained in 1922 and grown in the greenhouse the following winter showed typical symptoms of spindle-tuber. No mosaic symptoms were evident.. Part of these units were grown in the field in 1923. During the latter part of the summer some of the plants showed evidences of current season infection with mosaic. Some of the progeny of these plants were used in the previous experiments. One unit grown at 25° C. showed no mosaic symptoms during the first 4 to 6 weeks after planting, while very slight symptoms appeared during the later stages of growth. Table 5 presents the data obtained on 2 of these plants (Nos. 25 and 26) and these are representative of 8 plants in this unit. It is clearly evident that these spindle-tuber plants were infected with mild mosaic in the field the previous summer. It is also evident that if the tubers had been tested for mosaic in the greenhouse at a high temperature, no mosaic would have been detected until the plant was half mature (Plate 4, U25 and L25), and then the symptoms would have been hardly discernible. The same fact has often been observed in "indexing" seed in the greenhouse. It is not possible to grow a plant from a single eye to a height of 10–15 cm. and then to be certain that the tuber is not infected.

Plants from the same original units as the above, grown in other plots in the field in 1923, showed entirely different symptoms when grown in the greenhouse the following winter. Typical examples are shown in Table 5, plants Nos. 21 and 22. It is clearly evident that these spindle-tuber plants became affected with other diseases in the field. The effect of the change of temperature on the symptoms is also apparent.

While such combinations have often been recorded when plants are exposed to infection in the open field, they have

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s of plants infected with new diseases the previous year and the splitting up of disease combinations in other plants

Foliage	Symptoms[1]																	Remarks
	Dwarfing	Chlorosis	Mottling	Wrinkling	Ruffling	Rugosity	Curling	Rolling	Uprightness	Rigidity	Brittleness	Spotting	Streaking	Burning	Leaf-dropping	Early death	Tuber symptoms[3]	
SPINDLE-TUBER																		
all	..	..	0	0	1	..	..	..	2	..	..	..	..	..	..	..		Pl.4U25-L25.Evidently was infected with mild mosaic the previous y'r.
old	..	..	0	0	1	..	..	..	2	..	..	..	..	..	..	..		
new	..	..	2	2	2	..	..	..	2	..	..	..	..	..	..	..	1	
all	..	..	1d[2]	..	1	..	..	..	2	..	..	..	..	..	..	..	3	No symptoms until 6 weeks after emergence.
all	..	..	3	3	3	2	2	..	2	2	2	1	1	1	1	..		Evidently infected with rugose mosaic the previous year.
old	..	..	2	3	3	0	0	..	2	2	0	1	1	1	1	..		
new	2	..	2d	1	2	0	0	..	2	2	0	0	0	0	0	..	2	
all	2	..	3	3	3	1	2	..	2	..	..	1	1	1	1	..	1	
SPINDLE-TUBER + MILD MOSAIC																		
all	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	1	Plate 7, A.
all	1	..	..	2	1	1	1	..	..	..	..	..	..	..	..	..	2	Plate 7, B.
all	2	..	3	3	3	3	3	..	..	..	..	1	1	2	3	..	2	Plate 7, C.
all	..	..	3	3	2	..	..	1	2	2	..	..	..	..	..	..		Plate 7, D.
old	..	..	1	2	2	..	..	0	2	0	..	..	..	..	..	..		
new	..	..	0	1	1	..	..	0	2	0	..	..	..	..	..	..	3	

[1]*d* = diffuse mottling. [2]See Table 2, footnote 2.

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never been found to occur on plants grown under insect cages where each single disease has always remained true to type.

The problem of diagnosing and studying these diseases is, however, often complicated by the fact that a plant affected with a combination of diseases not only may acquire another disease but may show a splitting up of these diseases in the different tubers produced or even in different eyes of the same tuber, as shown by the following example.

Plants Nos. 35, 36, 37, and 40, listed in Table 5, (Plate 7), were all originally from the same tuber in 1922, listed as spindle-tuber + mild mosaic, which when grown in the greenhouse and in the field in 1923 showed the symptoms to be expected in this combination. The plants were exposed to infection in the field in 1923, however, and the progeny when grown in the greenhouse in 1924 showed not only a splitting up of this combination but also the acquisition of new symptoms.

Plants Nos. 36 and 37 were grown from two halves of the same tuber and plant No. 35 from another tuber in the same hill; No. 40 was grown from an adjacent hill in the same unit. No symptoms of mosaic appeared on plant No. 36 grown at 15° C. Spindle-tuber could be detected in both the tops and the tubers in the mature plant. Plant No. 37 from the same mother tuber grown at the same temperature showed not only symptoms of mosaic as occurred in the preceding generation and spindle-tuber in the new tubers, but also marked rugosity, curling, spotting, streaking, burning, and leaf-dropping, as shown in Plate 7. The plant had apparently become infected with another disease, probably rugose mosaic, but this disease had not affected all the eyes in the tuber.

Plant No. 35 from another tuber from the same hill showed no symptoms of mosaic, and neither the foliage nor the tubers produced showed any serious evidences of spindle-tuber.

Plant No. 40, from an adjacent hill in the same unit.

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the greenhouse produced the symptoms shown in Table 3, plants Nos. 5 and 6 (Plate 3, B). The most marked symptoms were the severe rolling and brittleness of the leaves at 15° C. and an entire absence of curling, streaking, burning, and leaf-dropping which had been present in the preceding generation.

DISCUSSION

The experimental results clearly show that of the environmental factors studied, light, soil moisture, and soil temperature have very little or no effect whatever upon the foliage symptoms of any of the degeneration diseases investigated. High soil moistures and high soil temperatures appeared to increase the severity of the tuber symptoms of the spindle-tuber disease. However, there is a tendency for healthy and mosaic tubers likewise to change in shape and color at high soil temperatures and appear somewhat similar to spindle-tuber potatoes.

The effect of air temperatures on the foliage symptoms of mosaic has again been found to be very pronounced and appears to be the most important factor in the masking of foliage symptoms of the degeneration diseases.

Mottling was again found to be the most constant symptom of mosaic at all temperatures, altho a change in the type and degree of mottling was clearly evident. With mild mosaic, mottling did not appear on new growth at 25° C., while the distinct mottling occurring at 15° became very indistinct or diffuse when the plants were changed to 25°. The indistinct or diffuse mottling of plants affected by rugose mosaic was not greatly changed at high temperatures.

The wrinkling, ruffling, rugosity, curling, rolling, and brittleness of mosaic plants all tended to disappear at 25° C. In addition to the masking of the above symptoms which has previously been recorded it was found that the streaking, spotting, burning, and leaf-dropping of rugose mosaic did not occur at 25° C. on Bliss Triumphs.

The symptoms of mild mosaic are so greatly masked at high temperatures that the plant often looks healthy while the other mosaic types and combinations of two mosaics or mosaic and spindle-tuber still retain enough of the symptoms at 25° C. to clearly distinguish them from mild mosaic and healthy plants. The identification of the individual disease, however, is very difficult and often impossible at 25° C.

The spindle-tuber disease reacts to temperature the exact reverse of mosaic. Plants affected with spindle-tuber were

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often impossible to distinguish when grown at low temperatures, whereas the symptoms became increasingly evident as the temperature was raised. It was noticeable that ruffling, which is a leaf symptom of both mild mosaic and spindle-tuber, disappears at high temperatures with mild mosaic, while the reverse occurs with the same symptoms on spindle-tuber plants.

The symptoms of the various diseases were much more evident on plants of the Green Mountain variety than on Bliss Triumph, and the masking of symptoms at high temperatures was not nearly as great with Green Mountains.

The correlation of the results obtained in greenhouse experiments with conditions existing in the field was made in a previous publication, and the application of these results is being made in the seed potato industry in the state. The results obtained by the use of constant temperatures in the greenhouse have been found comparable to those obtained with similar mean temperatures occurring in the field. In determining the amount of mosaic in fields being grown for certification in Nebraska it has been found impossible to rely entirely upon disease readings made in the field, as the normal temperature conditions during most of the season cause considerable masking of the symptoms. Accordingly representative samples of all lots of seed are planted in western Nebraska very early and mosaic readings made on the plants in these plots when the weather conditions are favorable for the appearance of the symptoms. Even this practice does not always permit the detection of all the mosaic present, so duplicate samples of all seed planted for certification are grown in Louisiana under more favorable conditions for the appearance of the disease. If more than a specified percentage of mosaic is found to occur in either of these plots, the field being grown from the same seed is disqualified for certification[1] even tho the disease is not detected in the commercial field. It has also been found advisable to make inspections in the field at the most favorable time for the appearance of the diseases, depending on date of planting and weather conditions rather than upon set dates, and to increase the number of field inspections to at least three.

Another application of our knowledge of the masking of symptoms is also found in the usual method of indexing tubers

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in the greenhouse. The authors have found it necessary to grow such indexed plants nearly to maturity under two different temperatures. The plants are started at about 15° C. and mosaic readings made at that temperature; when the plant is about half grown the temperature is raised to 22°–25° and spindle-tuber readings are made both on the tops and on the tubers, which can be dug before maturity in order to expedite the work. It was found that the first readings made in all these experiments when the plants were 10 to 15 cm. high were not very reliable, owing to the frequent abnormal appearance of the first leaves of healthy plants, and the apparent presence of symptoms which did not remain constant on mosaic plants and which could not be correlated with the disease known to be present. The second reading, made two weeks after the first, was found to be the most accurate reading of the disease symptoms. The high temperature indexing has been found necessary to detect the spindle-tuber disease.

While mosaic is a serious disease, especially in seed potato growing sections, it is not nearly as serious as the spindle-tuber problem in Nebraska. Spindle-tuber either alone or in combination with mosaic has always been found to reduce yields much more than any one type of mosaic. The disease also greatly retards sprouting, thus reducing the stand and resulting in a further reduction of the yield.

The combination of two or more diseases on the same plant further complicates the problem. In Nebraska it is these combinations containing spindle-tuber that are the real menace to the seed potato industry. The addition of new diseases to plants subject to infection in the field has been a matter of common occurrence. The splitting up of these combinations into separate and distinct diseases is not as common, but it has been observed even in plants grown from different portions of the same seed tuber.

It has been clearly evident in these investigations that the various types of degeneration diseases described by Schultz and Folsom do come true to type by tuber perpetuation. The similarity of some of these diseases to diseases of the same nature described by other investigators and the possible duplication of names is a question which does not properly belong in this paper. It was impossible to obtain material from European investigators[1] for a comparison of the diseases described and named by them with those of Schultz and Folsom. The identity and relation of these diseases one with the other can only be determined by cross inoculation studies

[1] Because of the federal quarantine act.

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of plants growing under similar conditions. The casual description of a disease, without a statement of the environmental conditions occurring, results in considerable confusion. A statement of the symptoms occurring on some of the plants used in these experiments, without reference to the temperature at which they were grown, certainly would not allow for the identification of the disease. This is clearly illustrated in the data presented on the yellow dwarf disease, which has been held by some to be simply a synonym for a combination of two diseases previously described.

Yellow dwarf appeared as a disease distinct from any of the others studied. The effect of air temperature on the symptoms of this disease was even more marked than with mosaic, and the action was the reverse of that occurring with mosaic. At 15° C. the symptoms both on the tops and in the tubers were not evident, whereas the plants grown at 25° were severely diseased, early death resulted, and the tubers were badly diseased. The disease was not transmitted thru the soil to Bliss Triumph in the few tests made. This disease is not known to occur in Nebraska at the present time.

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PLATE 1

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PLATE 2

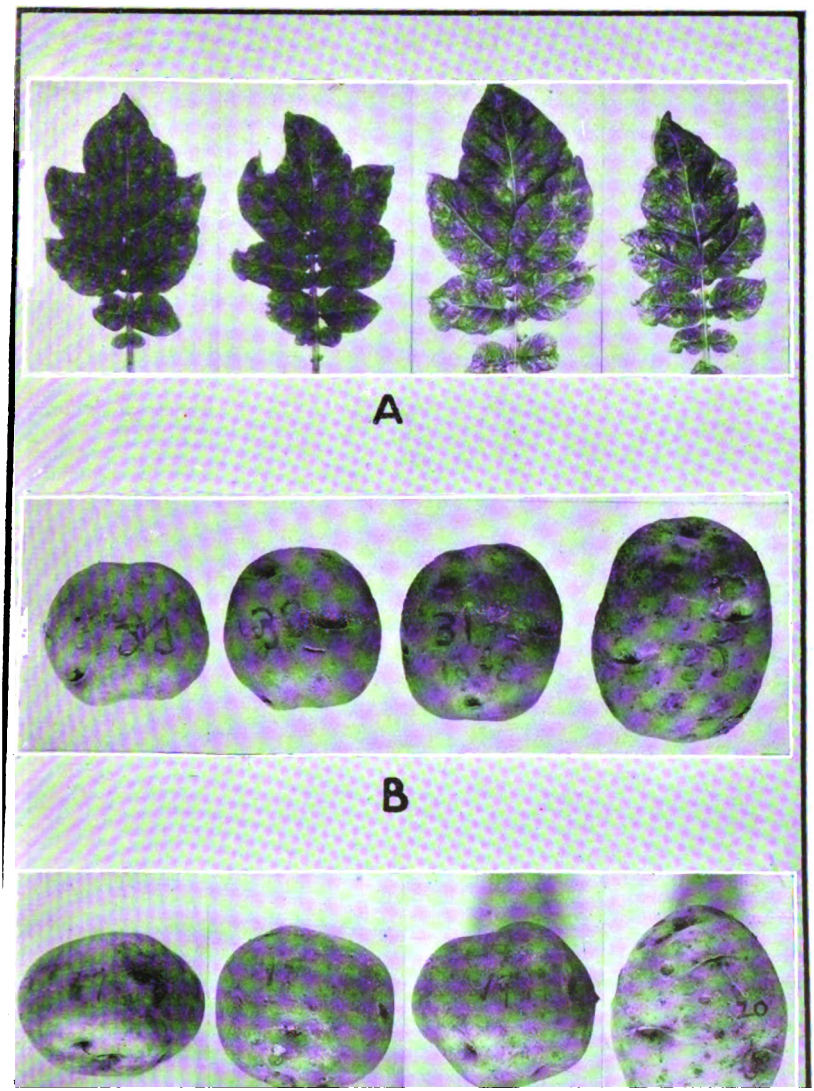

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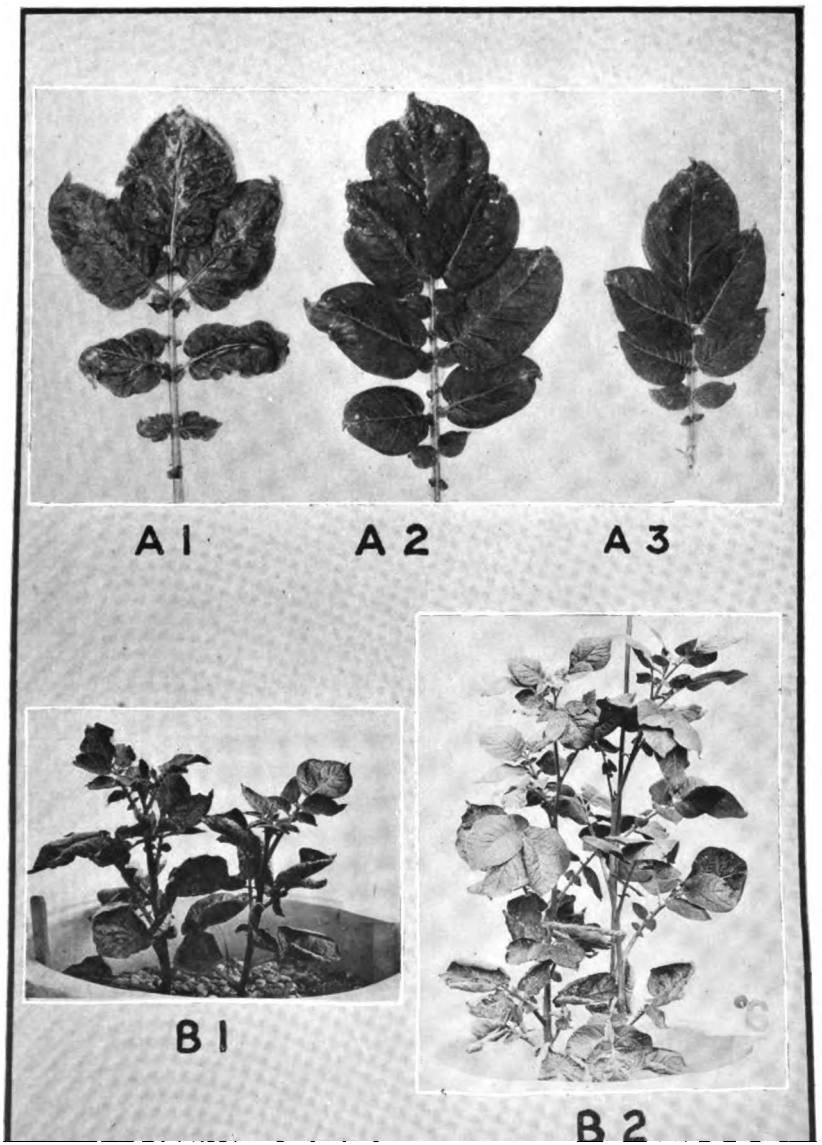
PLATE 3



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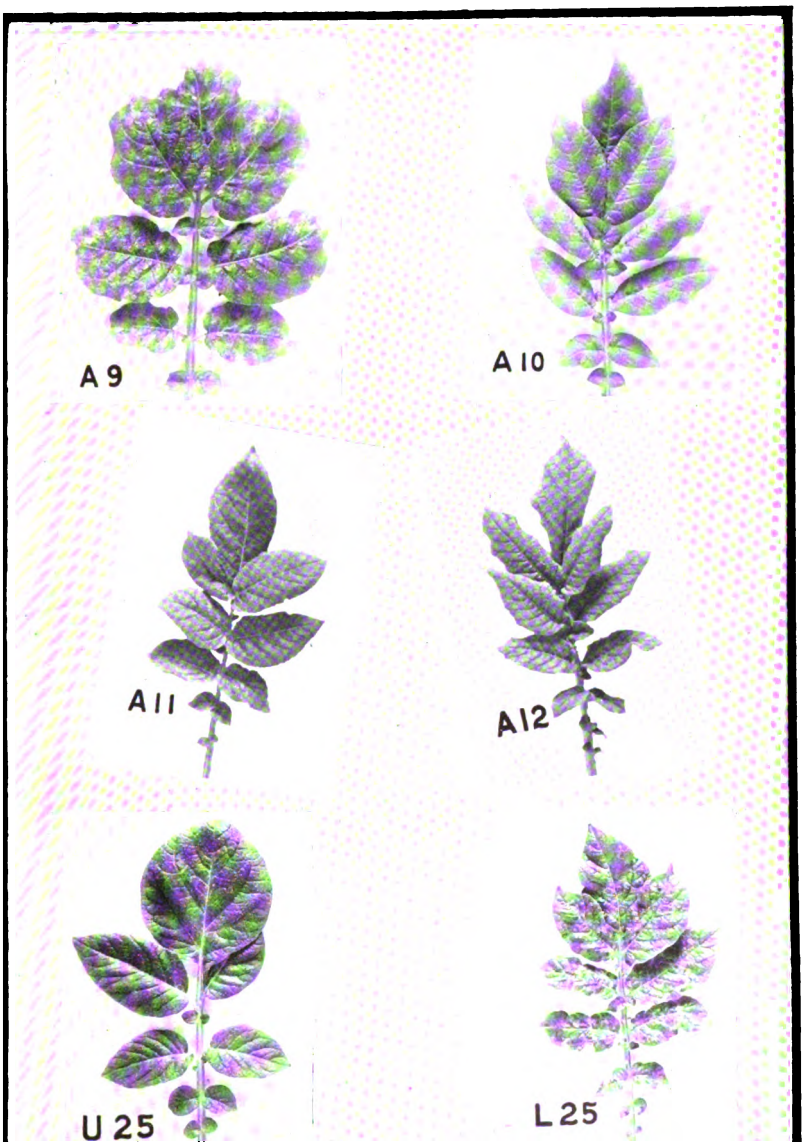

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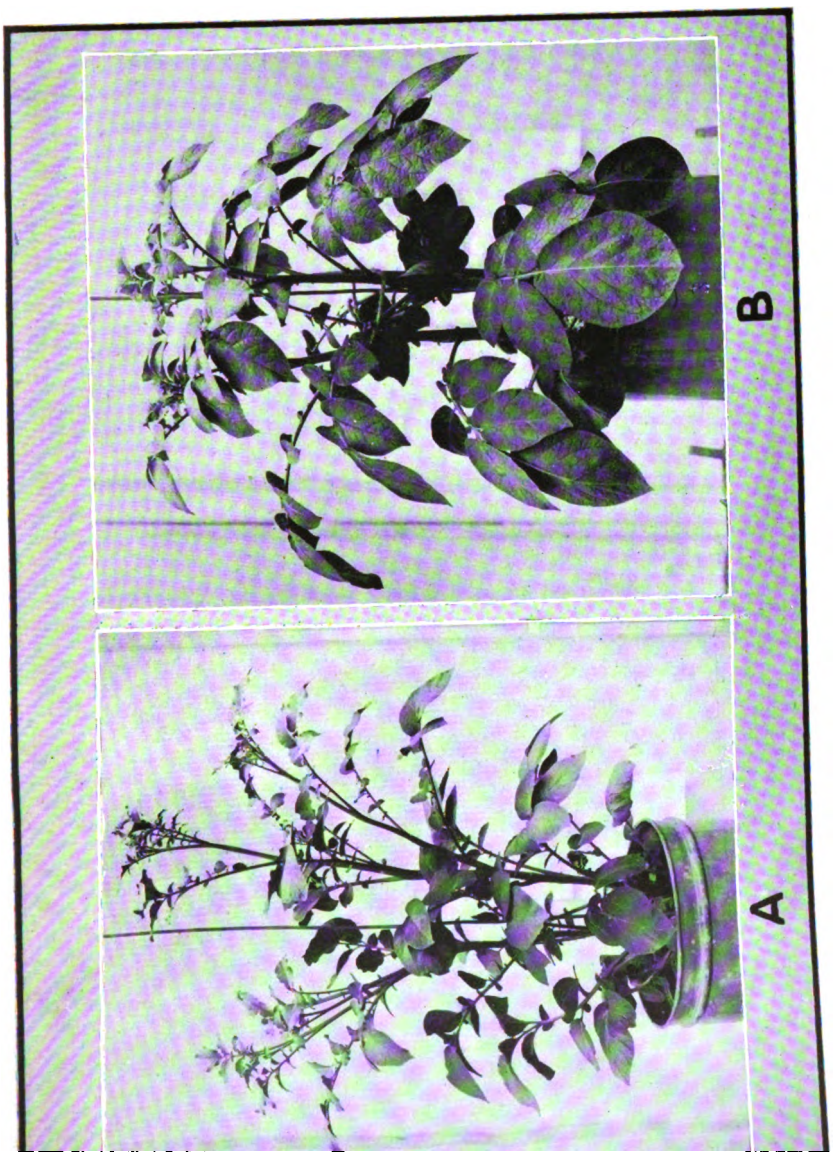
PLATE 5



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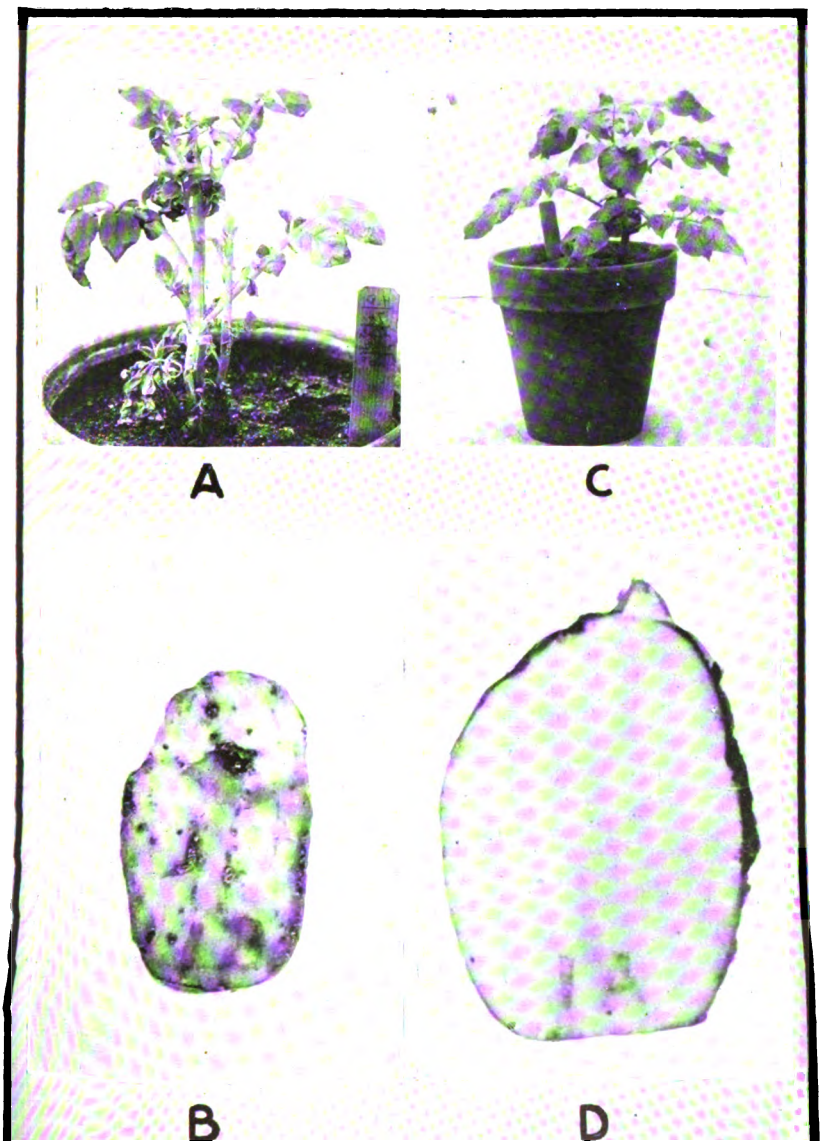

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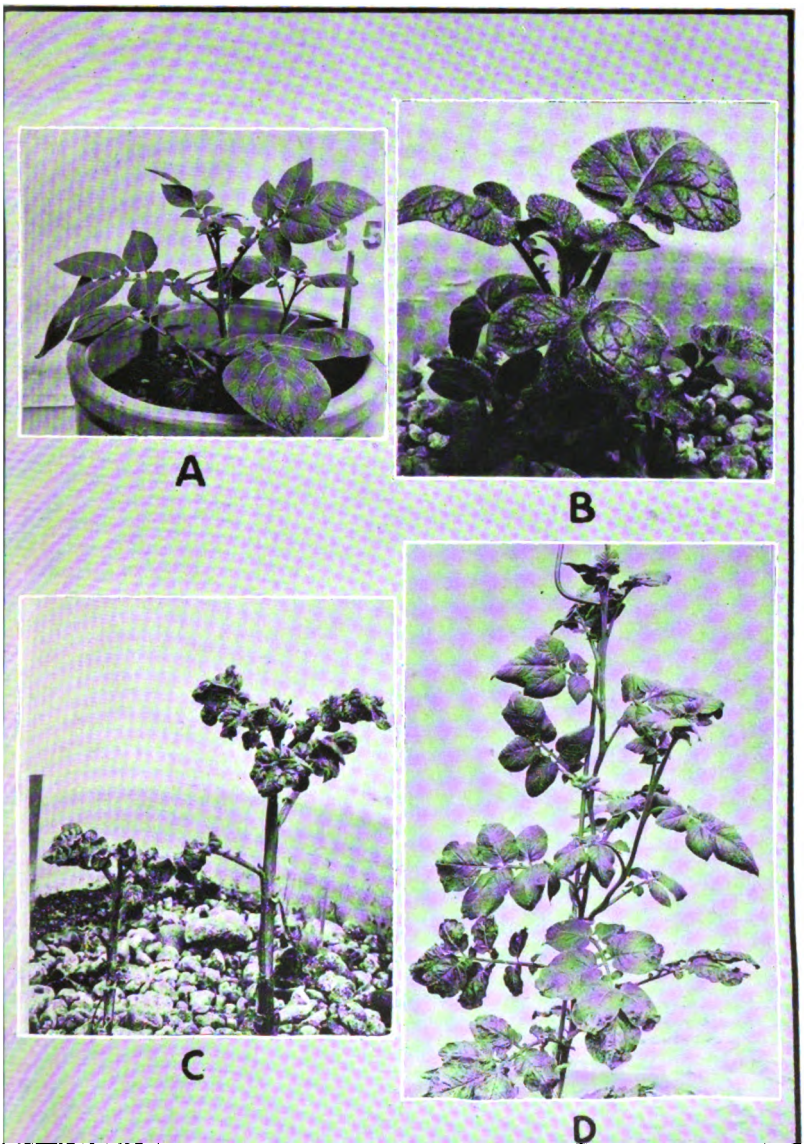

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COLLEGE OF AGRICULTURE UNIVERSITY OF NEBRASKA
AGRICULTURAL EXPERIMENT STATION
RESEARCH BULLETIN 30

An Inquiry Into the Cause of the Increase of Tuberculosis of Swine

By L. VAN ES AND H. M. MARTIN

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An Inquiry Into the Cause of the Increase of Tuberculosis of Swine

By L. VAN ES AND H. M. MARTIN

Tuberculosis of swine has, as a rule, been looked upon as being transmitted from cattle either thru the feeding of milk products or thru the agency of the manure of feeding yards occupied by both hogs and cattle. This has been the accepted theory of the origin of swine tuberculosis and no doubt it was based upon substantial experimental evidence at the time of its conception and for a considerable period after that. While it was known for some years that swine were occasionally found to contract tuberculosis thru direct or indirect contact with tuberculous poultry, such occurrences, at least in this country, were looked upon as more or less infrequent incidences and even as late as 1923 Mohler (46) reported that: "It is believed that the area eradication work among cattle will eventually eliminate tuberculosis from swine as the greatest source of infection in swine is known to be through following diseased cattle or drinking unpasteurized skim milk from creameries."

In the face of a lack of any volume of evidence contrary to this view it was generally shared by animal pathologists and livestock sanitarians of this country, and the elimination of swine tuberculosis became a very important, altho somewhat secondary objective of the efforts looking forward to the eradication of the bovine disease.

The meat inspection returns for a number of years, however, pointed strongly to the possibility that some factor or factors other than bovine infection operating in the recognized manner may play an etiologic part in the production of swine tuberculosis. Not only do those data fail to show any degree of parallelism between the incidence of bovine and swine tuberculosis, but they present the picture of a very wide divergence for the two types of the disease which were thought to be so closely correlated.

As shown by the graphs represented in Figs. 1 and 2 which were projected from the data submitted in Tables 1 and 2, the curve representing the total retentions on account of tuberculosis in cattle, gently declining or inclining remains,

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on the whole, close to a horizontal position and during no one year does the number of retentions amount to much more than 27 per thousand animals slaughtered. The curve showing the number of animals condemned, even more closely adhering to a certain level, on the whole follows the curve representing the retentions.

In the graph, based upon the tuberculosis data pertaining to swine, the curve representing the number of condemnations per thousand animals slaughtered is even more level and

TABLE 1.—*Number of cattle slaughtered during period 1907-1922 and number of animals retained and condemned. (Table prepared from data published in Yearbook of U. S. Department of Agriculture for 1922, p. 217.)*

Year	Slaughtered	Retained		Condemned	
		No.	*Per 1000*	*No.*	*Per 1000*
1907[1]	5,867,642	24,876	4.23	17,117	2.91
1908	7,116,275	68,395	9.61	24,371	3.42
1909	7,325,337	100,650	13.74	24,525	3.34
1910	7,962,189	123,501	15.51	27,638	3.47
1911	7,781,030	133,551	17.16	27,186	3.49
1912	7,532,005	160,122	21.27	35,273	4.68
1913	7,155,816	152,560	21.31	33,001	4.61
1914	6,724,117	143,699	21.36	29,738	4.42
1915	6,964,402	158,239	22.72	32,644	4.68
1916	7,404,288	190,991	25.79	37,085	5.00
1917	9,299,489	218,928	23.53	46,351	4.98
1918	10,938,287	222,787	20.38	40,692	3.90
1919	11,241,991	205,698	18.31	37,600	3.35
1920	9,709,819	200,917	20.70	37,762	3.99
1921	8,179,572	173,658	21.35	33,328	4.19
1922	7,871,457	212,978	27.05	38,804	4.93

[1]Covers 9 months from October 1, 1906, to June 30, 1907.

stable during the period studied than the same curve dealing with cattle tuberculosis, practically ranging only between one and two per thousand. On the other hand the curve pertaining to swine retained for tuberculosis shows a marked rise from the beginning of the period to the last, with the exception of the slight decline for the year 1919. The number of retentions of swine on account of tuberculosis per thousand animals slaughtered rose from 13.83 in 1907 to 163.87 in 1922. Thus there apparently took place in the period, 1907-1922, an increase of close to 150 per 1,000 hogs

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slaughtered, of a type of tuberculosis not sufficiently progressive to lead to the condemnation of the carcasses.

No doubt improvements in the technique of meat inspection may be responsible for a greater number of retentions, but under a system of meat inspection operating under the same general rules and supervision, marked differences in their relative number for cattle and swine can not reasonably be expected if a greater proficiency of inspectors were the only factor to be considered in this problem.

TABLE 2.—*Number of swine slaughtered during period 1907-1922 and number of animals retained and condemned. (Table prepared from data published in Yearbook of United States Department of Agriculture for 1922, p. 217.)*

Year	Slaughtered	Retained		Condemned	
		No.	*Per 1,000*	*No.*	*Per1,000*
1907[1]	26,189,026	362,445	13.83	48,544	1.85
1908	35,113,077	719,279	20.48	77,554	2.20
1909	35,427,931	860,425	24.28	45,113	1.27
1910	27,656,021	792,176	28.64	28,880	1.04
1911	29,916,363	1,117,789	37.36	31,517	1.08
1912	34,966,378	1,643,100	47.00	42,267	1.21
1913	32,287,538	1,809,751	56.05	47,632	1.47
1914	33,289,705	2,201,005	66.11	48,252	1.44
1915	36,247,958	2,774,835	76.55	66,023	1.82
1916	40,482,799	3,687,817	91.09	74,109	1.83
1917	40,210,847	3,978,168	98.93	76,807	1.91
1918	35,449,247	3,494,587	98.58	59,740	1.68
1919	44,398,389	4,103,376	92.42	65,837	1.48
1920	38,981,914	4,262,719	109.35	65,609	1.68
1921	37,702,866	4,693,305	124.48	64,830	1.71
1922	34,416,439	5,640,061	163.87	70,304	2.04

[1]Covers 9 months from October 1, 1906, to June 30, 1907.

While during the period under consideration the rate of cattle retentions as compared with condemnations increased 3.7 times, those in swine multiplied 10.8 times under the same meat inspection practices.

This great increase in the number of swine found to be tuberculous presented a problem, the solution of which appeared to be desirable before adequate control measures could be devised or recommended. In the hope that a solution of the problem may be found this station undertook an investigation and attempted by experimental inquiry to deter-

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mine the infection type of the tuberculosis associated with the animals which constituted the bulk of the retentions.

In view of the apparent increased incidence and spread of tuberculosis among poultry in a large hog raising section, of which Nebraska forms a part, the experimental project mentioned was to a large extent so directed as to prove or disprove the hypothesis that avian infection may at least in part be held accountable for the great morbidity rate for tubercu-

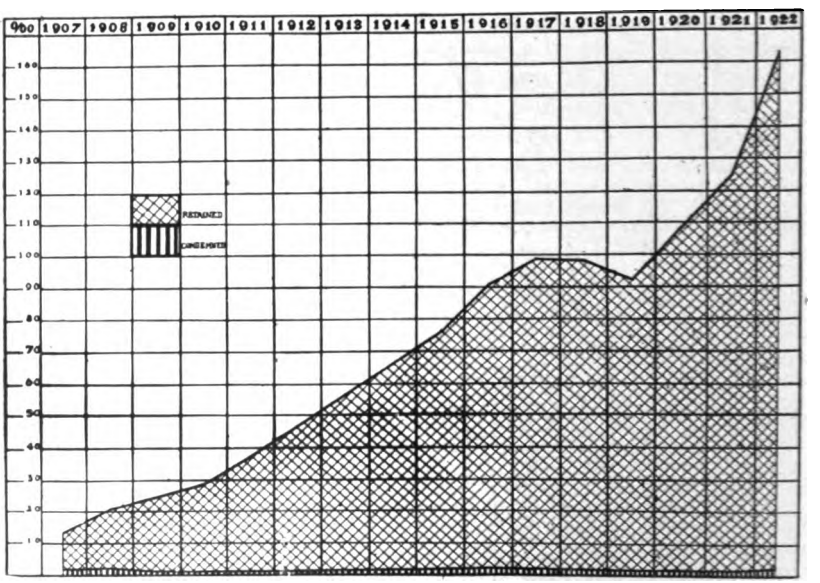

FIG. 1.—Retentions and condemnations, on account of tuberculosis, per 1000 head of swine slaughtered between 1907 and 1922.

losis among swine and its marked increase during the last fifteen years.

Evidence that avian infection may cause tuberculosis in swine and that the pathogenicity of the avian type of the tubercle bacillus is not strictly confined to birds has grown in volume since 1904 when Weber and Bofinger (53) demonstrated for the first time the presence of avian tubercle bacilli in the caseous lymphnodes of a three-months-old pig which was otherwise entirely free from tuberculosis.

Much of the early work, such as that by Gilbert and Roger (28), Cadiot, Gilbert and Roger (11), Courmont and Dor

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(17), Maffucci (42), Vignal (51), Kossel, Weber and Heuss (39), and Rabinowitch (47), as well as some of a later date by Koch and Rabinowitch (38), Bang (3), Zwick (54), De Haan (9), Bang (4), Arloing (1), De Jong (22-23), Carl (13), and Zwick and Zeller (55) pertain largely to the relation of the avian to the mammalian type of infection and vice versa, and helped to establish a definite technique of differentiation between the two types. As practically all the

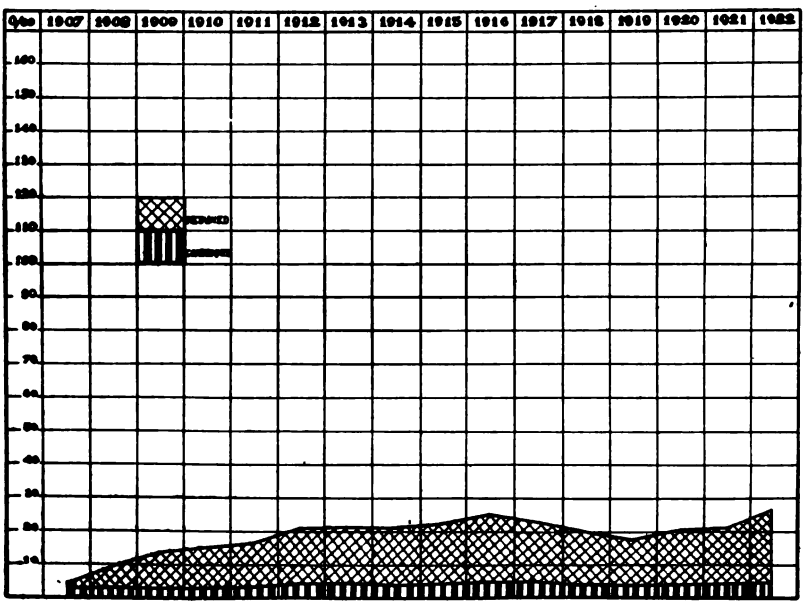

FIG. 2.—Retentions and condemnations, on account of tuberculosis, per 1000 head of cattle slaughtered between 1907 and 1922

observations made concerned the smaller laboratory animals and fowls they did not disclose the fact that avian infection, aside from poultry, was to be considered as a source of infection to other farm animals.

The susceptibility of swine to avian tuberculosis was first shown by De Jong (20) in 1905, who 5 years later (21) reported a case of spontaneous infection which had produced a generalized tuberculosis necessitating the condemnation of the carcass. He concluded from his observations and experiments that swine belong to a category of mammals susceptible

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to both mammalian and avian tuberculosis. Titze (49) and Kersten and Ungermann (37) on the other hand either failed to transmit avian tuberculosis to swine or could not demonstrate its presence in the tuberculous hogs examined. Weber (54) did not care to exclude the possibility of avian infection in swine, but like Eber (27) did not appear to attach much importance to it.

Mohler and Washburn (44-45) of this country demonstrated the susceptibility of swine to poultry tuberculosis and reported an outbreak in Oregon where apparently a spontaneous transmission had taken place. In 1911 the British Royal Commission on tuberculosis (48) reported that of 59 cases of tuberculosis of swine of which the type of infection was definitely determined, 5 cases showed avian infection, while in another the avian as well as the bovine bacillus were jointly associated with the lesions.

Bang (5-6) found evidence indicating the transmission of tuberculosis to swine from an infected flock of poultry and observed further that infected swine gave a stronger reaction to avian tuberculin than to a tuberculin prepared with bacilli of the human type. According to this author avian tuberculosis is accountable for a part of the swine tuberculosis encountered in Denmark. This opinion found ample support in the work of Christiansen (14-15) who typed the bacilli found in 118 hogs and demonstrated the presence of avian infection in 86 animals, of the bovine type in 28 animals, while those found in the remaining 4 were classified as atypical. The importance of an avian source of infection in dealing with tuberculosis in swine in Denmark is further emphasized by Bang and Holm (7), Brieg (8-9-10), and others.

Eastwood and Griffith (26) found avian infection in 9 of the 34 animals comprising one group examined and in 17 of another group of 59 tuberculous swine.

The importance of the avian type of tubercle bacillus as a cause of hog tuberculosis is further emphasized by Junack (35-36), Joest (33), Douma (25), Day (18), De Jong (24), and Helm (30).

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ent, the fact would not escape attention. While it was assumed that if mammalian types were found, they would be of bovine origin, the scheme of investigation provided for their further typing in case they were found frequently enough to be regarded as factors in the increase of the incidence of swine tuberculosis. The results of the inquiry, however, were such as to render the further typing of the mammalian bacilli quite unnecessary.

The typing was entirely accomplished by the use of animal inoculations. Altho a number of strains were isolated and brought under cultivation, preference was given to the use of cavias and fowls in order to bring to light the different pathogenic characters of the organisms present in the material studied.

This material consisted almost entirely of the cervical and mesenteric lymphnodes of swine affected with the more or less non-progressive forms of tuberculosis, which are the preponderating causes for retentions at abattoirs and which group is more than any other responsible for the increased incidence of swine tuberculosis since 1907.

The lymphnodes were secured through the courteous and efficient co-operation of the inspectors in charge of the Federal Meat Inspection Stations of Omaha, Nebraska; Nebraska City, Nebraska; Sioux City, Iowa, and St. Joseph, Missouri, who also indicated the origin of the swine from which the material was obtained. All the material used in the experiment was obtained from Nebraska swine with the exception of one consignment which came from a South Dakota shipment.

The latter detail was deemed advisable in order to secure, if possible, surveys of the livestock on the farms of origin. Unfortunately this proved to be possible in only a very few instances.

As soon as practicable after the arrival of the material the caseous material of the lymphnodes was removed, examined for bacilli, and brought in suspension for inoculation purposes. Two or more cavias were injected subcutaneously in the inner face of the thigh, while two or more fowls were injected intravenously with the same suspension. In addition, the fowls were permitted to eat a quantity of what was left of the lymphnodes after the removal of the caseous material. At times trouble was encountered on account of the presence of septic organisms in the lymphnodes which resulted in the premature deaths of the cavias and very rarely also of

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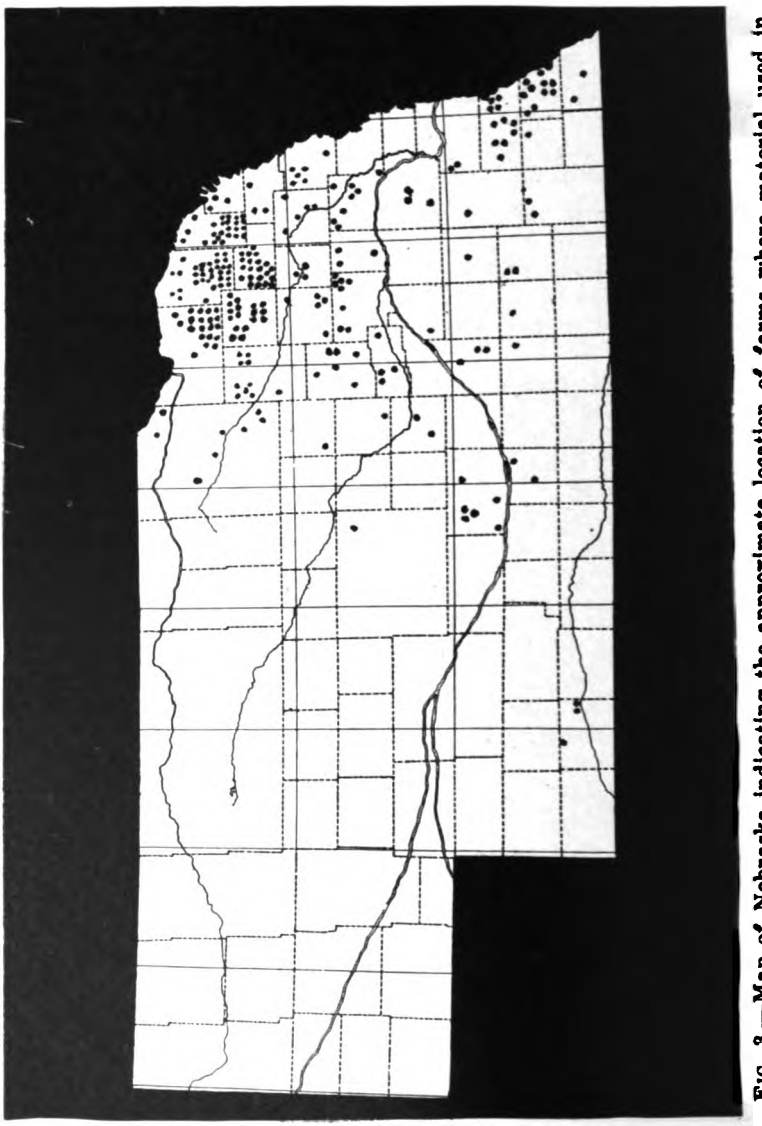

FIG. 3.—Map of Nebraska indicating the approximate location of farms where material used in the inquiry originated

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the fowls. Treatment with very weak solutions of antiformin was always successful in the prevention of such accidents. In a number of instances a repetition of the inoculation experiments became necessary on account of the occurrence of fatal disease among the guinea pigs. Looking forward to such contingencies, a part of the original infective material, kept in cold storage, was always held available until termination of each experiment.

The fowls used as test animals were nearly all obtained from the station flock in which no tuberculosis had occurred for at least 6 years. As an additional precaution against the presence of spontaneous disease, all birds entering into the experiment were tested with avian tuberculin. No chickens were procured in the open market and the few not supplied by the station were purchased out of private flocks.

The inoculated animals were permitted to live for approximately 3 months, unless any of those infected with the same material died earlier and showed unmistakable evidence of tuberculous infection. In such a case the remaining cavias and fowls would be killed and examined, provided that not less than 8 weeks had passed since the inoculation. No animals were killed and their condition accepted as experimental evidence after a shorter period.

The autopsy results enabled the writers to distinguish certain definite groups among the material examined which in their opinion justified the following classifications:

Group I: Negative results. In the experiments ranged under this division, tuberculosis was not produced in any of the animals inoculated. In all probability the bacilli of the original lesions had died or were present only in such small numbers as to be incapable of producing disease.

Group II: Infection due to a mammalian type of tubercle bacilli. As the base for classification under this group served the fact that the guinea pigs as a result of the inoculation developed a marked, generalized, progressive tuberculosis, while the fowls inoculated with the same material remained entirely free from tuberculous lesions or the latter consisted only of one or two strictly localized, small, non-progressive, indurated, or caseous nodules.

Group III: Infection caused by the avian type of Bacillus tuberculosis. If the inoculation caused a manifest, marked, or extensive tuberculosis in the fowls and failed to produce either any lesions at all in the cavias, or such as were so en-

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tirely localized, non-progressive, and small as to cause no disturbance in the animal's health or well-being, the results were accepted as evidence of infection by the avian type of bacillus and of a transmission of tuberculosis from poultry to swine.

Group IV: Infection of probable avian origin. In a small number of the cases the inoculation experiments resulted in the production of one or two small, isolated, non-progressive nodules in the fowls, while no lesions of any kind could be demonstrated in the cavias. The writers regard such lesions as being due to avian infection, but on account of the possibility that a similar lesion could readily have been missed in the cavia, it was thought wise to include this type of results in a separate group.

Group V: Infection resulting in the development of tuberculosis in both cavias and fowls. Results of this nature were classified as due to a mixture of mammalian and avian types of bacilli. The term "mixed types" is used largely because it is convenient. There is, however, no reason to doubt the existence of ambivirulent strains of tubercle bacilli entirely capable of producing tuberculoses of identical severity and type in guinea pigs as well as fowls. In the experiments reported at this time, no attempt was made to pursue this question any further and hence this group may include infection results by the simultaneous action of avian and mammalian types of bacilli, by the action of mammalian types also capable of producing a marked tuberculosis in fowls, or by the action of avian types endowed also with pathogenic qualities toward cavias.

Here follow statements pertaining to each lymphnode consignment received and examined, to the inoculation results observed, and to the classification of the infection type of each shipment of swine from which the material was obtained:

No. 3188. A shipment of 56 hogs by F. M., Platte County. Tuberculosis in 21 animals. Lesions in cervical and mesenteric lymphnodes.

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No. 3189. A shipment of 59 hogs by A. F., Custer County. Tuberculosis in 6 animals. Lesions in cervical and mesenteric lymphnodes. Bacilli present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A marked tuberculosis of liver and spleen in one fowl and a less extensive infection in the other. In the lesions of the former, bacilli were plentiful but very scarce in those of the latter.

Classification of infection type = Avian.

No. 3199. A shipment of 66 hogs by J. R. K., Stanton County. Tuberculosis in 5 animals. Lesions in cervical lymphnodes only. Bacilli present in lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative or doubtful.

Classification of infection type = Undetermined.

No. 3266. A shipment of 57 hogs by L. B. M., Holt County. Tuberculosis in 6 animals. Lymphnode lesions only.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Developed marked or extensive tuberculosis of liver and spleen in which bacilli were numerous.

Classification of infection type = Avian.

No. 3279. A shipment of 68 hogs by D. O'S., South Dakota. Tuberculosis in 46 animals. Lesions in cervical and mesenteric lymphnodes. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Slight tuberculous lesions developed in liver and spleen in which bacilli were present.

Classification of infection = Avian.

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No. 3445. A shipment of 51 hogs by E. N., Dodge County. Tuberculosis in 28 animals. Lesions in cervical and mesenteric lymphnodes in which bacilli were found to be present.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Slight lesions in one fowl only. Bacilli present in the lesions.

Classification of infection type = Probably avian.

No. 3477. A shipment of 83 hogs by T. E. K., Holt County. Tuberculosis in 15 animals. Bacilli found to be present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis of the liver and spleen of one fowl. Bacilli present in the lesions, but not numerous. The other fowl showed no evidence of disease.

Classification of infection type = Avian.

No. 3499. A shipment of 82 hogs by R. A. G., Buffalo County. Tuberculosis in 16 animals. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	In one fowl no lesions could be found. The other one showed one tuberculous nodule in the spleen in which bacilli could be shown.

Classification of infection type = Probably avian.

No. 3500. A shipment of 65 hogs by F. S., Holt County. Tuberculosis in 13 animals. Bacilli could be shown in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	In one fowl lesions could not be found, while in the other liver and spleen showed a marked tuberculosis with an abundance of bacilli present in the lesions.

Classification of infection type = Avian.

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No. 3553. A shipment of 60 hogs by G. R., Cuming County. Tuberculosis in 37 animals. Lesions of cervical and mesenteric lymphnodes.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked or extensive tuberculosis of liver and spleen. Bacilli very numerous in the lesions.

Classification of infection type = Avian.

No. 3610. A shipment of 13 hogs by G. R., Nemaha County. Tuberculosis in three animals. Slight calcareous lesions in cervical lymphnodes in which bacilli were present.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of spleens and livers. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 3611. A shipment of 11 hogs by W. H. K., Nemaha County. Tuberculosis in 3 animals. Slight caseo-calcareous lesions of cervical lymphnodes in which bacilli were present.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis of livers and spleens in which enormous masses of bacilli could be shown.

Classification of infection type = Avian.

No. 3612. A shipment of 3 hogs by A. M., Nemaha County. Tuberculosis in one animal. Slight caseo-calcareous lesions in cervical and mesenteric lymphnodes. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	One fowl showed no lesions and the other one only one small nodule in the spleen in which bacilli were numerous.

Classification of infection type = Probably Avian.

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No. 3614. A shipment of 10 hogs by H. C. S., Otoe County. Tuberculosis in 2 animals. Slight lesions in the cervical lymphnodes and well marked or extensive caseo-calcareous lesions of the mesenteric lymphnodes. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Slight tuberculous lesions of spleen and liver in which bacilli were present.

Classification of infection type = Avian.

No. 3615. A shipment of 5 hogs by P. B., Otoe County. Tuberculosis in 2 animals. Slight lesions of the cervical lymphnodes and well marked or extensive caseo-calcareous lesions of the mesenteric lymphnodes. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of livers and spleens. Bacilli were plentiful in the lesions.

Classification of infection type = Avian.

No. 3616. A shipment of 7 hogs by H. H., Johnson County. Tuberculosis in 3 animals. Slight caseo-calcareous lesions of cervical lymphnodes in which bacilli were found to be present.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis of livers and spleens. Bacilli were plentiful in the lesions.

Classification of infection type = Avian.

No. 3617. A shipment of 17 hogs by F. M., Otoe County. Tuberculosis in 3 animals. Slight and extensive lesions in cervical, bronchial, portal, and mesenteric lymphnodes and in lungs, liver and spleen. Bacilli were found to be present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	One fowl showed no lesions and the other one a slight tuberculosis of the liver, in the lesions of which bacilli were present in abundance.

Classification of infection type = Avian.

No. 3618. A shipment of 15 hogs by P. K. Nemaha County. —

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No. 3619. A shipment of 7 hogs by P. F. N., Otoe County. Tuberculosis in 3 animals. Slight or slightly caseo-calcareous lesions in liver and in cervical, bronchial, portal, and mesenteric lymphnodes. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis of spleens and livers in the lesions of which bacilli were present.

Classification of infection type = Avian.

No. 3629. A shipment of 62 hogs by G. J., Thurston County. Tuberculosis in 19 animals, cervical lymphnodes affected in 14 and mesenteric lymphnodes in 5 animals. All lesions were old and calcareous and bacilli could scarcely be found in them.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative in one fowl while the other showed 3 small tuberculous nodules in which bacilli could not be found.

Classification of infection type = Probably Avian.

No. 3701. A shipment of 65 hogs by J. L., Stanton County. Tuberculosis in 8 animals. Slight lesions of cervical and mesenteric lymphnodes in which bacilli could be found.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked and extensive tuberculosis of livers and spleens. Bacilli could be shown in the lesions.

Classification of infection type = Avian.

No. 3732. A shipment of 63 hogs by N. V. P., Burt County. Tuberculosis in 26 animals; cervical lesions shown in 15 and mesenteric lesions in 11 animals. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of livers and spleens. Bacilli present in the lesions.

Classification of infection type = Avian.

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No. 3931. A shipment of 45 hogs by C. F. F., Madison County. Tuberculosis in 34 animals. Bacilli present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Extensive, generalized and progressive tuberculosis in both cavias. Material contained but few bacilli.	Negative

Classification of infection type = Mammalian.

No. 3999. Tuberculous mesenteric lymphnodes from a hog affected with hog cholera examined for C. W. M., Cass County. Bacilli present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of spleens and livers. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4006. Tuberculous mesenteric lymphnodes of a hog affected with hog-cholera submitted by W. D., Cass County. Bacilli were abundant in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of livers in the lesions of which bacilli were present.

Classification of infection type = Avian.

No. 4032. A shipment of 61 hogs by P. C. A., Wayne County. Tuberculosis in 17 animals: 11, cervical lymphnodes; 5, mesenteric lymphnodes; one, cervical and mesenteric lymphnodes. Bacilli were found to be plentiful in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of livers and spleens with bacilli present in the lesions.

Classification of infection type = Avian.

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No. 4133. A shipment of 48 hogs by C. C., Buffalo County. Tuberculosis in 3 animals. Slight lesions of the cervical lymphnodes in which bacilli were present.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis of both fowls. Lesions in livers, spleens, lungs, and cervical lymphnodes. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4143. A shipment of 4 hogs by J. G., Nemaha County. Tuberculosis in 2 animals. Extensive lesions of liver, and lungs, and cervical, bronchial, portal, and mesenteric lymphnodes. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Tuberculosis in all 4 cavias, but only in one was the disease generalized and progressive	Negative

Classification of infection type = Mammalian.

No. 4144. A shipment of 25 hogs by D. E. W., Richardson County. Tuberculosis in 13 animals. Slight lesions of cervical and mesenteric lymphnodes. The lesions contained many bacilli.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of livers and spleens with bacilli present in the lesions.

Classification of infection type = Avian.

No. 4145. A shipment of 5 hogs by A. F. D., Otoe County. Tuberculosis of one animal. Slight lesions of cervical lymphnodes. Bacilli were present in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

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No. 4147. A shipment of 4 hogs by L. E., Nemaha County. Tuberculosis in one animal. Slight lesions of cervical lymphnodes in which bacilli were present.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

No. 4148. A shipment of 22 hogs by L. A., Nemaha County. Tuberculosis in 6 animals. Lesions in lungs and liver and in cervical, bronchial, portal, and mesenteric lymphnodes. Bacilli were present in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Generalized, progressive tuberculosis in 3 cavias, while the fourth presented no lesions.	One fowl presented an isolated nodule in the spleen while the other showed marked tuberculosis of the liver, several nodules in the spleen, and a few in the intestine. Bacilli were present in the lesions.

Classification of infection type = Mixed.

No. 4149. A shipment of 8 hogs by F. H., Otoe County. Tuberculosis in 2 animals. Slight lesions of cervical lymphnodes. Bacilli could not be found in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

No. 4150. A shipment of 6 hogs by C. W., Nemaha County. Tuberculosis in 3 animals. Slight lesions of cervical lymphnodes. Bacilli were not found in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis of both fowls. Bacilli present in the lesions.

Classification of infection type = Avian.

No. 4151. A shipment of 10 hogs by H. M., Nemaha County. Tuberculosis in 3 animals. Slight lesions of cervical lymphnodes. Bacilli could not be found in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

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No. 4152. A shipment of 11 hogs by W. G., Otoe County. Tuberculosis in 2 animals. Slight lesions of cervical and mesenteric lymphnodes. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of spleens and livers of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4153. A shipment of 15 hogs by A. L., Otoe County. Tuberculosis of 4 animals. Lesions of cervical and mesenteric lymphnodes. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis in both fowls. Lesions in liver, spleen, kidneys, and lungs. Bacilli plentiful in the lesions.

Classification of infection type = Avian.

No. 4163. A shipment of 79 hogs by E. H. W., Otoe County. Tuberculosis in 5 animals. Lesions of cervical lymphnodes. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

No. 4193. Lesions from 3 hogs which had reacted to a tuberculin test. The lesions were slight and bacilli were scarce in them. Hogs owned by G. H., Buffalo County.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A slight tuberculosis of the liver and spleen of one fowl and extensive tuberculous lesions in those of the other fowl. Bacilli were present in the lesions.

Classification of infection type = Avian.

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No. 4388. A shipment of 68 hogs by F. U., Madison County. Tuberculosis in 13 animals. Slight lesions of cervical and mesenteric lymphnodes. Bacilli were found to be numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis of both fowls. Lesions in liver, spleen, lungs, and mesentery. Bacilli were very numerous in the lesions.

Classification of infection type = Avian.

No. 4409. A shipment of 9 hogs by W. M. M., Otoe County. Tuberculosis in 6 animals. Lesions in cervical and mesenteric lymphnodes in which bacilli were numerous.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis of both fowls. Lesions in spleen, liver, lungs, gall bladder, and mesentery. Bacilli numerous in the lesions.

Classification of infection type = Avian.

No. 4414. A shipment of 56 hogs by E. H., Cuming County. Tuberculosis in 10 animals. Lesions in cervical lymphnodes in 9 and in mesenteric lymphnodes in one animal. A few bacilli were present in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Slight tuberculosis of the livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4416. A shipment of 70 hogs by M. J., Boyd County. Tuberculosis in 26 animals. Lesions in cervical lymphnodes, 15; in mesenteric lymphnodes, 7; and in cervical and mesenteric ly[illegible]

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No. 4417. A shipment of 75 hogs by J. R. M., Holt County. Tuberculosis in 9 animals. Lesions in cervical lymphnodes in 7 and in mesenteric lymphnodes in 2. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis in both fowls. Lesions in livers, spleens, lungs, kidneys, and mesentery. Bacilli were very numerous in the lesions.

Classification of infection type = Avian.

No. 4418. A shipment of 64 hogs by F. S., Boone County. Tuberculosis in 11 animals. Lesions in cervical lymphnodes in 9 and in mesenteric lymphnodes in 2. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis of livers of both and the spleen of one fowl. Bacilli were plentiful in the material.

Classification of infection type = Avian.

No. 4423. A shipment of 71 hogs by G. H. S., Dodge County. Tuberculosis in 11 animals. Lesions in cervical lymphnodes in 5, in mesenteric lymphnodes in 4, and in cervical and mesenteric lymphnodes in 2. Bacilli were numerous in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis of livers and spleens of both fowls. Bacilli were very numerous in the lesions.

Classification of infection type = Avian.

No. 4424. A shipment of 72 hogs by H. E. R., Nance County. Tuberculosis of 17 animals. Lesions in cervical lymphnodes in 10, in mesenteric lymphnodes in 4, and in cervical and mesenteric lymphnodes in 3. Bacilli were numerous in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis in both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4425. A shipment of 50 hogs by H. J. N., Dodge County. Tuberculosis in 10 animals. Lesions in cervical lymphnodes in 9 and in mesenteric lymphnodes in one. Bacilli were present in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Generalized, progressive tuberculosis in 2 cavias and a more localized form of the disease in one.	A moderate degree of tuberculosis in both fowls. Bacilli were numerous in the lesions.

Classification of infection type = Mixed.

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No. 4437. A shipment of 68 hogs by W. S., Pierce County. Tuberculosis in 23 animals. Lesions in cervical lymphnodes in 21, and in mesenteric lymphnodes in 2. Bacilli were numerous in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Caseous lymphadenitis near inoculation point. Bacilli present in the material. No tuberculous lesions in any other part.	Very extensive tuberculosis of livers and spleens of both fowls. Bacilli numerous in the lesions.

Classification of infection type = Avian.

No. 4438. A shipment of 82 hogs by E. S., Pierce County. Tuberculosis in 29 animals. Lesions in cervical lymphnodes in 15, in mesenteric lymphnodes in 12, and in cervical and mesenteric lymphnodes in 2. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis of both fowls. Lesions in livers, spleens, and mesentery. Bacilli were very numerous in the material.

Classification of infection type = Avian.

No. 4446. A shipment of 73 hogs by W. P., Hamilton County. Tuberculosis in 7 animals. Lesions of cervical lymphnodes. Bacilli were present in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Slight degree of tuberculosis of the livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4456. A shipment of 61 hogs by J. C. C., Platte County. Tuberculosis in 26 animals. Lesions in cervical lymphnodes in 17, in mesenteric lymphnodes in 7, and in cervical and mesenteric lymphnodes in 2. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Very extensive tuberculosis of livers and spleens of both fowls, with bacilli very numerous in the lesions.

Classification of infection type = Avian.

No. 4474. A shipment of 64 hogs by F. F. P., Burt County. Tuberculosis in 8 animals. Lesions of cervical lymphnodes. Bacilli rather numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

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No. 4476. A shipment of 76 hogs by P. X. P., Burt County. Tuberculosis in 16 animals. Lesions in cervical lymphnodes in 9 and in mesenteric lymphnodes in 7. Bacilli numerous in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis in both fowls. Lesions in livers, spleens, and lungs. Bacilli were numerous in the lesions.

Classification of infection type = Avian.

No. 4483. A shipment of 74 hogs by E. S., Knox County. Tuberculosis in 6 animals. Slight lesions in cervical lymphnodes in which bacilli were numerous.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Slight tuberculous lesions in both fowls. A number of nodules in livers of both and spleen of one. Bacilli were plentiful in the lesions.

Classification of infection type = Avian.

No. 4506. A shipment of 58 hogs by S. P., Gage County. Tuberculosis in 8 animals. Slight lesions in cervical lymphnodes. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked or extensive tuberculosis of both fowls. Lesions in livers, spleens, and peritoneum. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4516. A shipment of 73 hogs by E. F., Pierce County. Tuberculosis in 11 animals. Lesions in cervical lymphnodes in 9, in mesenteric lymphnodes in one, and cervical and mesenteric lymphnodes in one. Bacilli were numerous in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis of livers and spleens of both fowls. Bacilli were numerous in the lesions.

Classification of infection type = Avian.

No. 4525. A shipment of 55 hogs by H. P., Platte County. Tuberculosis in 41 animals. Lesions in cervical lymphnodes in 34, in mesenteric lymphnodes 3, and in cervical and mesenteric lymphnodes 4. Bacilli were plentiful in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of livers and spleens of both fowls. Bacilli present in the lesions.

Classification of infection type = Avian.

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No. 4534. A shipment of 60 hogs by H. S., Gage County. Tuberculosis in 10 animals. Slight lesions in the cervical lymphnodes of 9 and in the mesenteric lymphnodes of one. Bacilli were present in the lesions in moderate numbers.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis of livers and spleens of both fowls. Bacilli were numerous in the lesions.

Classification of infection type = Avian.

No. 4536. A shipment of 76 hogs by J. S., Wayne County. Tuberculosis in 23 head. Lesions of cervical lymphnodes in 20 and of mesenteric lymphnodes in 3. Bacilli were very numerous in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
One cavia developed extensive tuberculosis of liver and spleen and lymphnodes. Another showed a nonprogressive or arrested tuberculosis and a third was found to be free of lesions.	Tuberculosis of both fowls. Lesions in livers and spleens with an abundance of bacilli.

Classification of infection type = Mixed.

No. 4543. A shipment of 63 hogs by H. G. L., Platte County. Tuberculosis in 8 animals. Lesions of cervical lymphnodes in 3, and of mesenteric lymphnodes in 5. Bacilli were plentiful in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Two small nodules in the spleen of one fowl. Bacilli present but scarce in the lesions.
	The other fowl presented no lesions.

Classification of infection type = Probably Avian.

No. 4550. A shipment of 62 hogs by A. A., Polk County. Tubercu-

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No. 4565. Some tuberculous lymphnodes of a hog slaughtered by I. W. P., Saunders County. Bacilli were very scarce in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Extensive, generalized, progressive tuberculosis of all 4 cavias. Bacilli present in the lesions.	Negative

Classification of infection type = Mammalian.

No. 4619. A shipment of 69 hogs by J. W. K., Boone County. Tuberculosis in 16 animals. Lesions in cervical lymphnodes in 5, in mesenteric lymphnodes in one, and in cervical and mesenteric lymphnodes in 10. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis in livers and spleens of both fowls, with bacilli numerous in the lesions.

Classification of infection type = Avian.

No. 4626. A shipment of 58 hogs by E. O., Lancaster County. Tuberculosis in 19 animals. Lesions of cervical lymphnodes in 12, in mesenteric lymphnodes in 6, and in cervical and mesenteric lymphnodes in one. Bacilli were numerous in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of both fowls. Lesions in spleens and livers. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4627. A shipment of 65 hogs by C. W. J., Boone County. Tuberculosis in 14 animals. Lesions of cervical lymphnodes in 7, and of mesenteric lymphnodes in 7. Bacilli were present in the lesions in moderate numbers.

INOCULATION RESULTS

Cavias	*Fowls*
Generalized, progressive tuberculosis in 2 cavias. Localized, nonprogressive tuberculosis in one cavia. Bacilli were present in all lesions.	Tuberculosis in both fowls. Lesions in spleens and livers. Bacilli were numerous in the lesions.

Classification of infection type = Mixed.

No. 4643. A shipment of 71 hogs by J. B. P., Burt County. Tuberculosis in 10 animals. Lesions in cervical lymphnodes in 7, in mesenteric lymphnodes in one, and in cervical and mesenteric lymphnodes in 2. Bacilli were present in the lesions in moderate numbers.

INOCULATION RESULTS

Cavias	*Fowls*
Marked, progressive, generalized tuberculosis in all cavias.	Slight tuberculosis of livers and spleens of both fowls, with bacilli present in the lesions either numerously or in moderate numbers.

Classification of infection type = Mixed.

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No. 4658. A shipment of 60 hogs by A. V., Colfax County. Tuberculosis in 40 animals. Lesions in cervical lymphnodes in 22, in mesenteric lymphnodes in 12, and in cervical and mesenteric lymphnodes in 6. Bacilli were numerous in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis in both fowls. Lesions in livers and spleens in which bacilli were numerous.

Classification of infection type=Avian.

No. 4659. A shipment of 64 hogs by F. P., Pierce County. Tuberculosis in 10 animals. Lesions in cervical lymphnodes in 8, and in mesenteric lymphnodes in 2. Bacilli were numerous in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked and extensive tuberculosis of both fowls. Lesions in livers and spleens. Bacilli very numerous in the lesions.

Classification of infection type=Avian.

No. 4668. A shipment of 60 hogs by W. B., Wayne County. Tuberculosis in 28 animals. Lesions in cervical lymphnodes in 23, in mesenteric lymphnodes in 3, in cervical and mesenteric lymphnodes in one, and generalized tuberculosis in one. Bacilli were numerous in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Very extensive tuberculosis in both fowls. Lesions in livers, spleens, and lungs. Bacilli present in the lesions.

Classification of infection type=Avian.

No. 4669. A shipment of 63 hogs by E. H., Dixon County. Tu-

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No. 4670. A shipment of 60 hogs by P. N. P., Buffalo County. Tuberculosis in 8 animals. Lesions in cervical lymphnodes. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Of the 3 cavias one showed a caseated lymphnode containing bacilli. No other lesions were found in those animals.	Marked or extensive tuberculosis in both fowls. Lesions in livers, spleens, and lungs. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4671. A shipment of 60 hogs by E. F., Knox County. Tuberculosis in 38 animals. Lesions in cervical lymphnodes in 29, in mesenteric lymphnodes in 4, and in cervical and mesenteric lymphnodes in 5. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A moderate degree of tuberculosis in both fowls. Lesions in livers and spleens. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4687. A shipment of 68 hogs by L. B. B., Cedar County. Tuberculosis in 35 animals. Lesions in cervical lymphnodes in 29, and in mesenteric lymphnodes in 6. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A moderate degree of tuberculosis in both fowls. Lesions in livers and spleens in which bacilli were found to be present.

Classification of infection type = Avian.

No. 4688. A shipment of 66 hogs by A. S. W., Cuming County. Tuberculosis in 7 animals. Lesions in cervical lymphnodes in 6 and in mesenteric lymphnodes in one. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

No. 4689. A shipment of 63 hogs by E. H., Dixon County. Tuberculosis in 8 animals. Lesions of cervical lymphnodes in 3, of mesenteric lymphnodes in 3, and of cervical and mesenteric lymphnodes in 2. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis of both fowls. Lesions of spleens and livers with bacilli present.

Classification of infection type = Avian.

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No. 4690. A shipment of 55 hogs by C. S., Burt County. Tuberculosis in 11 animals. Lesions of cervical lymphnodes in 4, of mesenteric lymphnodes in 5, and of cervical and mesenteric lymphnodes in 2. Bacilli were numerous in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A moderate degree of tuberculosis of livers and spleens of both fowls with bacilli present in the lesions.

Classification of infection type = Avian.

No. 4697. A shipment of 46 hogs by L. W. C., Thurston County. Tuberculosis in 6 animals. Lesions in cervical lymphnodes in 2, and in mesenteric lymphnodes in 4. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Very extensive tuberculosis in both fowls. Lesions in livers, spleens, and lungs. Bacilli were plentiful in the lesions.

Classification of infection type = Avian.

No. 4711. A shipment of 61 hogs by R. B., Hamilton County. Tuberculosis in 15 animals. Lesions in cervical lymphnodes in 10, and in mesenteric lymphnodes in 5. Bacilli were very numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A moderate degree of tuberculosis of the spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4712. A shipment of 54 hogs by H. W. M., Dodge County. Tuberculosis in 7 animals. Lesions in cervical lymphnodes in 5, and in mesenteric lymphnodes in 2. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis of both fowls. Lesions in livers and spleens. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4713. A shipment of 63 hogs by G. W., Cuming County. Tuberculosis in 30 animals. Lesions of cervical lymphnodes in 10, of mesenteric lymphnodes in 12, and in cervical and mesenteric lymphnodes in 8. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis of the livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

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No. 4718. A shipment of 60 hogs by H. A. K., Platte County. Tuberculosis in 15 animals. Lesions in cervical lymphnodes in 12, in mesenteric lymphnodes in 2, and in cervical and mesenteric lymphnodes in one. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Very extensive tuberculosis in both fowls. Lesions in livers, spleens, and lungs. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4723. A shipment of 58 hogs by J. J. B., Saunders County. Tuberculosis in 16 animals. Lesions in cervical lymphnodes in 12, and in mesenteric lymphnodes in 4. Bacilli were very numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis of both fowls. Lesions in livers and spleens. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4761. Tuberculous cervical lymphnodes from hogs shipped by J. S., Hitchcock County. Very slight lesions in which bacilli were exceedingly scarce.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

No. 4767. A shipment of 63 hogs by R. P., Cedar County. Tuberculosis in 24 animals. Lesions in cervical lymphnodes in 14, in mesenteric lymphnodes in 7, and in cervical and mesenteric lymphnodes 3. Bacilli were found to be present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis of livers and spleens of both fowls. Bacilli were very numerous in the lesions.

Classification of infection type = Avian.

No. 4768. A shipment of 60 hogs by A. B., Wayne County. Tuberculosis in 19 animals. Lesions in cervical lymphnodes in 16, in mesenteric lymphnodes in one, and in cervical and mesenteric lymphnodes in one. One animal sterilized. Bacilli found to be present in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative, with exception of some non-progressive lesions in the spleen of one of the 4 cavias.	Very extensive tuberculosis of the livers and spleens of both fowls. Bacilli were found to be present in the lesions.

Classification of infection type = Avian.

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No. 4769. A shipment of 65 hogs by A. F., Dixon County. Tuberculosis in 56 animals. Lesions in cervical lymphnodes in 42, in mesenteric lymphnodes in 2, in mesenteric and cervical lymphnodes 4. Animals sterilized 4 and animals condemned 4. Bacilli were present in the lesions in moderate numbers.

INOCULATION RESULTS

Cavias	*Fowls*
Marked or extensive, generalized, and progressive tuberculosis in the 4 cavias. Bacilli were found to be present in the lesions.	Negative

Classification of infection type = Mammalian.

No. 4770. A shipment of 60 hogs by B. F. M., Antelope County. Tuberculosis in 4 animals. Lesions in cervical lymphnodes in 3 and in the mesenteric lymphnodes in one. Bacilli were found to be present in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative with the exception of a small necrotic area in the liver of one of the cavias. In this lesion one bacillus only could be found.	Very slight tuberculous lesions in the livers of both fowls. Only in one fowl could bacilli be found to be present in moderate numbers.

Classification of infection type = Probably Avian.

No. 4771. A shipment of 60 hogs by W. C. P., Antelope County. Tuberculosis in 7 animals. Lesions in cervical lymphnodes in 6, and in mesenteric lymphnodes in one. The presence of bacilli in this material was very doubtful.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

No. 4772. A shipment of 77 hogs by F. L., Dixon County. Tuberculosis in 9 animals. Lesions of cervical lymphnodes only. Bacilli were probably present in the material, but very scarce and difficult to be recognized as such.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

No. 4773. A shipment of 63 hogs by S. H., Dakota County. Tuberculosis in 14 animals. Lesions in cervical lymphnodes in 9, and in mesenteric lymphnodes in 5. Bacilli were found to be numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Very extensive tuberculosis of both fowls. Lesions in livers, spleens, and lungs. Bacilli were numerous in the lesions.

Classification of infection type = Avian.

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No. 4789. Tuberculous lymphnodes of swine shipped by G. B., Hitchcock County. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis of livers and spleens of both fowls. Bacilli were numerous in the lesions.

Classification of infection type = Avian.

No. 4792. A shipment of 62 hogs by H. R. N., Dixon County. Tuberculosis in 24 animals. Lesions in cervical lymphnodes in 20, and in mesenteric lymphnodes in 4. Bacilli were found to be numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis of both fowls. Lesions in livers, spleens, and mesentery. Bacilli were abundant in the lesions.

Classification of infection type = Avian.

No. 4793. A shipment of 74 hogs by H. M., Cedar County. Tuberculosis in 28 animals. Lesions in cervical lymphnodes in 16, in mesenteric lymphnodes in 6, and in cervical and mesenteric lymphnodes in 6. Bacilli were very numerous in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative with the exception of a small necrotic focus in the liver of one cavia in which bacilli could be found. A localized, non-progressive lesion.	Extensive tuberculosis of livers and spleens of both fowls. Bacilli were numerous in the lesions.

Classification of infection type = Avian.

No. 4794. A shipment of 65 hogs by C. T., Cedar County. Tuberculosis in 17 animals. Lesions in cervical lymphnodes in 11, in mesenteric lymphnodes in 5, and in cervical and mesenteric lymphnodes in one. Bacilli were numerous in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Marked and extensive, generalized, progressive tuberculosis of both cavias. Bacilli were present in the lesions.	Negative

Classification of infection type = Mammalian.

No. 4795. A shipment of 63 hogs by R. L., Cedar County. Tu-

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No. 4796. A shipment of 76 hogs by J. L., Knox County. Tuberculosis in 4 animals. Lesions of cervical lymphnodes only. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A slight tuberculosis of livers and spleens of both fowls. Bacilli were found to be present in the lesions.

Classification of infection type = Avian.

No. 4797. A shipment of 64 hogs by C. M. M., Antelope County. Tuberculosis in 13 animals. Lesions in cervical lymphnodes in 4, in mesenteric lymphnodes in 2, and in cervical and mesenteric lymphnodes in 7. Bacilli were found to be very numerous in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4807. A shipment of 67 hogs by J. H., Knox County. Tuberculosis in 15 animals. Lesions in cervical lymphnodes in 13 and in mesenteric lymphnodes in 2. Bacilli were found to be very numerous in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Very extensive and marked tuberculosis of both fowls. Lesions in livers and spleens. Bacilli were found to be present in the lesions.

Classification of infection type = Avian.

No. 4808. A shipment of 43 hogs by S. N. D., Kearney County. Tuberculosis in 10 animals. Lesions in cervical lymphnodes in 8 and in mesenteric lymphnodes in 2. Bacilli were very numerous in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of both fowls. Lesions in livers, spleens, and lungs. Bacilli were present in the lesions.

Classification of infection type = Avian.

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No. 4815. A shipment of 51 hogs by H. J. H., Pierce County. Tuberculosis in one animal. Lesions in cervical lymphnodes only. Bacilli were numerous in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Very extensive tuberculosis of livers and spleens of both fowls. Bacilli were found to be present in the lesions.

Classification of infection type = Avian.

No. 4816. A shipment of 62 hogs by E. B., Wayne County. Tuberculosis in 11 animals. Lesions in cervical lymphnodes only. The presence of bacilli in this material was doubtful.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

No. 4817. A shipment of 69 hogs by H. S., Pierce County. Tuberculosis in 2 animals. Lesions in mesenteric lymphnodes only. Bacilli were scarce in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

No. 4818. A shipment of 66 hogs by A. S., Knox County. Tuberculosis in 3 animals. Lesions in cervical lymphnodes only. The presence of bacilli in this material was doubtful.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

No. 4829. A shipment of 70 hogs by A. J. E., Dixon County. Tuberculosis in 28 animals. Lesions in cervical lymphnodes in 16, in mesenteric lymphnodes in 7, and in cervical and mesenteric lymphnodes in 5. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis of the spleen and livers of both fowls. Bacilli were numerous in the lesions.

Classification of infection type = Avian.

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No. 4830. A shipment of 69 hogs by C. A. J., Dixon County. Tuberculosis of 11 animals. Lesions in cervical lymphnodes in 9 and in mesenteric lymphnodes in 2. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis in both fowls. Lesions in livers, spleens, and intestine. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4835. A shipment of 67 hogs by W. R., Dixon County. Tuberculosis of 14 animals. Lesions in cervical lymphnodes in 7 and in mesenteric lymphnodes in 7. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative in one fowl while in the other one a nodule was found in the liver in which bacilli were present.

Classification of infection type = Probably Avian.

No. 4836. A shipment of 25 hogs by D. H., Dixon County. Tuberculosis in 17 animals. Lesions in cervical lymphnodes in 4 and in mesenteric lymphnodes in 13. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked or extensive tuberculosis of the livers and spleens of both fowls. Bacilli were numerous in the lesions.

Classification of infection type = Avian.

No. 4837. A shipment of 53 hogs by G. A. J., Dixon County. Tuberculosis in 20 animals. Lesions in cervical lymphnodes in 13 and in mesenteric lymphnodes in 7. Bacilli were present in the lesions in moderate numbers.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis of both fowls. Lesions in spleens and livers. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4861. A shipment of 71 hogs by O. E. M., Dixon County. Tuberculosis in 5 animals. Lesions in cervical lymphnodes only. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis of both fowls. Lesions in livers and spleens in which bacilli were found to be present.

Classification of infection type = Avian.

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No. 4862. A shipment of 72 hogs by C. C. B., Cedar County. Tuberculosis in 6 animals. Lesions in cervical lymphnodes only. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
A marked tuberculosis of both cavias, but apparently the disease was not progressive. Bacilli could not be found in the lesions.	Marked tuberculosis of both fowls. Lesions in livers, spleens, and lungs. Bacilli were present in the lesions.

Classification of infection type = Mixed.

No. 4863. A shipment of 37 hogs by A. S., Knox County. Tuberculosis in 2 animals. Lesions in cervical lymphnodes only. As the lesions were of an extremely doubtful character and no bacilli could be found this material was discarded.

No. 4864. A shipment of 61 hogs by T. S., Dakota County. Tuberculosis in 21 animals. Lesions in cervical lymphnodes only. Bacilli were very numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Very extensive tuberculosis of the livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4865. A shipment of 81 hogs by A. B., Cedar County. Tuberculosis in 8 animals. Lesions in cervical lymphnodes in 7 and in mesenteric lymphnodes in one. Bacilli were very numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4866. A shipment of 71 hogs by G. H., Cedar County. Tuberculosis in 11 animals. Lesions in cervical lymphnodes in 10 and in mesenteric lymphnodes in one. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of livers and spleens of both fowls. Bacilli were found to be present in the lesions.

Classification of infection type = Avian.

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No. 4867. A shipment of 60 hogs by M. B., Knox County. Tuberculosis in 28 animals. Lesions in cervical lymphnodes in 26 and in mesenteric lymphnodes in 2. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked and very extensive tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4868. A shipment of 30 hogs by E. N., Knox County. Tuberculosis in 7 animals. Lesions in cervical lymphnodes only. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A moderate degree of tuberculosis in both fowls. Lesions of livers and spleens. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4869. A shipment of 66 hogs by C. A. B., Knox County. Tuberculosis in 3 animals. Lesions in cervical lymphnodes only. Bacilli could not be found in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

No. 4870. A shipment of 68 hogs by L. F. S., Dixon County. Tuberculosis in 4 animals. Lesions in cervical lymphnodes only. Bacilli present in the lesions in moderate numbers.

INOCULATION RESULTS

Cavias	*Fowls*
Extensive, progressive, generalized tuberculosis in all 3 cavias. Bacilli scarce in the lesions.	A moderate degree of tuberculosis in livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Mixed.

No. 4871. A shipment of 66 hogs by C. E. E., Pierce County. Tuberculosis in 5 animals. Lesions only in cervical lymphnodes. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Both cavias died with marked tuberculosis after one month following inoculation. Bacilli were numerous in the material.	Both fowls developed small, local lesions in about 10 weeks time. Bacilli were extremely rare in the lesions.

Classification of infection type = Mammalian.

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No. 4872. A shipment of 73 hogs by N. F. T., Dixon County. Tuberculosis in 4 animals. Doubtful lesions in cervical lymphnodes only. Bacilli could not be found in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

No. 4881. A shipment of 66 hogs by A. G., Cedar County. Tuberculosis in 4 animals. Lesions in cervical lymphnodes. Bacilli were very numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A moderate degree of tuberculosis of both fowls. Lesions in livers and one spleen. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4882. A shipment of 42 hogs for B. B., Cedar County. Tuberculosis in 6 animals. Lesions in cervical lymphnodes only. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis in livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4883. A shipment of 53 hogs by R. H. T., Cedar County. Tuberculosis in 4 animals. Lesions in cervical lymphnodes only. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis in both fowls. Lesions in livers and spleens. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4909. A shipment of 69 hogs by F. T., Dixon County. Tuberculosis in 6 animals. Lesions in cervical lymphnodes in 5 and in mesenteric lymphnodes in one. Bacilli could not be found in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

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No. 4910. A shipment of 39 hogs by W. P., Wayne County. Tuberculosis in 17 animals. Lesions in cervical lymphnodes in 9, in portal lymphnodes in one, and in mesenteric lymphnodes in 7. Bacilli were found to be present in the lesions in moderate numbers.

INOCULATION RESULTS

Cavias	*Fowls*
Marked, generalized, progressive tuberculosis in the cavia. Bacilli were present in moderate numbers.	One fowl showed slight tuberculous lesions of the spleen in which bacilli were extremely rare. The other fowl presented no lesions.

Classification of infection type = Mammalian.

No. 4911. A shipment of 67 hogs by W. G., Pierce County. Tuberculosis in 19 animals. Lesions in cervical lymphnodes in 14 and in mesenteric lymphnodes in 5. Bacilli were very numerous in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis of both fowls. Lesions in livers and spleens. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4912. A shipment of 75 hogs by A. A. S., Cedar County. Tuberculosis in 19 animals. Lesions in cervical lymphnodes in 11 and in mesenteric lymphnodes in 8. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Very extensive tuberculosis of both fowls. Lesions of livers, spleens, lungs, and peritoneum. Bacilli were abundant in the lesions.

Classification of infection type = Avian.

No. 4913. A shipment of 70 hogs by C. J. F., Wayne County. Tu-

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No. 4921. A shipment of 77 hogs by C. S., Antelope County. Tuberculosis in 16 animals. Lesions in cervical lymphnodes only. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis of livers and spleens of both fowls. Bacilli were numerous in the lesions.

Classification of infection type=Avian.

No. 4922. A shipment of 71 hogs by S. & N., Wayne County. Tuberculosis in 14 animals. Lesions in cervical lymphnodes in 13 and in mesenteric lymphnodes in one. Bacilli were present in the lesions in moderate numbers.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Slight tuberculosis in the livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type=Avian.

No. 4923. A shipment of 70 hogs by W. Bros., Knox County. Tuberculosis in 6 animals. Lesions in cervical lymphnodes only. Bacilli were very scarce in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type=Undetermined.

No. 4924. A shipment of 60 hogs by A. W. M., Dixon County. Tuberculosis in 18 animals. Lesions in cervical lymphnodes in 12 and in mesenteric lymphnodes in 6. Bacilli were very numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Very extensive tuberculosis in both fowls. Lesions in livers, spleens, lungs, and kidneys. Bacilli were numerous in the material.

Classification of infection type=Avian.

No. 4925. A shipment of 72 hogs by F. W., Wayne County. Tuberculosis in 21 animals. Lesions in cervical lymphnodes in 19 and in mesenteric lymphnodes in 2. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis of livers and spleens of both fowls. Bacilli were numerous in the lesions.

Classification of infection type=Avian.

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No. 4926. A shipment of 66 hogs by C. T., Pierce County. Tuberculosis in 8 animals. Lesions in cervical lymphnodes in 5 and in mesenteric lymphnodes in 3. Bacilli were very numerous in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of both fowls. Lesions in liver and spleens. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4930. A shipment of 34 hogs by A. P., Wayne County. Tuberculosis in one animal. Lesions in cervical lymphnodes only. Bacilli were present in the material, but very scarce.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

No. 4938. Tuberculous lesions of hogs shipped by E. E. C., Clay County. Bacilli were very numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Very extensive tuberculosis of livers and spleens of both fowls. Bacilli were numerous in the lesions.

Classification of infection type = Avian.

No. 4948. A shipment of 60 hogs by E. E., Cedar County. Tuberculosis in 2 animals. Lesions in cervical lymphnodes only. The presence of bacilli in the lesions was quite doubtful.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

No. 4949. A shipment of 65 hogs by F. R., Wayne County. Tuberculosis in 18 animals. Lesions in cervical lymphnodes in 17 and in mesenteric lymphnodes in one. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A slight tuberculosis in both fowls. Lesions in livers and spleens. Bacilli were present in the lesions.

Classification of infection type = Avian.

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No. 4950. A shipment of 65 hogs by F. E. H., Cedar County. Tuberculosis in 2 animals. Lesions in cervical lymphnodes only. Bacilli were very numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked or extensive tuberculosis of livers and spleens of both fowls. Bacilli were numerous in the lesions.

Classification of infection type = Avian.

No. 4951. A shipment of 58 hogs by W. L., Wayne County. Tuberculosis in 11 animals. Lesions in cervical lymphnodes in 9 and in mesenteric lymphnodes in 2. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Very extensive tuberculosis of livers and spleens of both fowls. Bacilli were numerous in the lesions.

Classification of infection type = Avian.

No. 4964. A shipment of 70 hogs by O. O., Cedar County. Tuberculosis in 23 animals. Lesions in cervical lymphnodes in 15 and in mesenteric lymphnodes in 8. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	One fowl died prematurely of sepsis, showing no evidence of tuberculosis. The other one developed extensive tuberculosis of liver and spleen. Bacilli were present in the lesions.

Classification of infection type = Avian.

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No. 4966. A shipment of 71 hogs by B. W. R., Dixon County. Tuberculosis in 22 animals. Lesions in cervical lymphnodes in 21 and in mesenteric lymphnodes in one. Bacilli were very numerous in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis in both fowls. Lesions in livers and spleens. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4967. A shipment of 59 hogs by F. W., Cedar County. Tuberculosis in 11 animals. Lesions in cervical lymphnodes in 5 and in mesenteric lymphnodes in 6. Bacilli were numerous in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative in one fowl, and in the other there was a moderate degree of tuberculosis of liver and spleen. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4968. A shipment of 54 hogs by W. F. B., Cedar County. Tuberculosis in 10 animals. Lesions in cervical lymphnodes only. Bacilli were numerous in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis of the livers and spleens of both fowls. Bacilli were numerous in the lesions.

Classification of infection type = Avian.

No. 4969. A shipment of 46 hogs by O. L., Knox County. Tuberculosis in 8 animals. Lesions in cervical lymphnodes only. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
One cavia died prematurely and showed a caseous lymphnode near inoculation point. The other cavia died with an extensive tuberculosis of liver, spleen, and precrural lymphnodes. Bacilli were numerous in the material.	Extensive tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Mixed.

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No. 4970. A shipment of 72 hogs by J. J., Dixon County. Tuberculosis in 6 animals. Lesions in the cervical lymphnodes only. Bacilli were very numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis of livers and spleens of both fowls. Bacilli were numerous in the lesions.

Classification of infection type = Avian.

No. 4971. A shipment of 31 hogs by O. L., Wayne County. Tuberculosis in 6 animals. Lesions in cervical lymphnodes in 3 and in mesenteric lymphnodes in 3. Bacilli were very numerous in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked or extensive tuberculosis in both fowls. Lesions in livers, spleens, and mesentery. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4972. A shipment of 56 hogs by T. W., Dixon County. Tuberculosis in 5 animals. Lesions in cervical lymphnodes in 4 and in mesenteric lymphnodes in one. Bacilli were very numerous in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	One fowl died prematurely and showed no tuberculosis, and the other developed slight tuberculous lesions of the liver in which bacilli were numerous.

Classification of infection type = Avian.

No. 4973. A shipment of 56 hogs by J. McI., Dixon County. Tuberculosis in 4 animals. Lesions in cervical lymphnodes only. Bacilli were numerous in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4974. A shipment of 70 hogs by V. J., Dixon County. Tuberculosis in one animal. Lesions in cervical lymphnodes only. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

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No. 4975. A shipment of 45 hogs by C. B., Pierce County. Tuberculosis in one animal. Lesions in cervical lymphnodes only. Bacilli were present in the lesions but were atypical in form.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

No. 5002. Tuberculous lymphnodes of hogs shipped by A. Bros., Kearney County. The presence of bacilli was questionable.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

No. 5014. A shipment of 42 hogs by M. O. N., Dixon County. Tuberculosis in 6 animals. Lesions in cervical lymphnodes only. Bacilli were present in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis of livers and spleens of both fowls. Bacilli were numerous in the lesions.

Classification of infection type = Avian.

No. 5015. A shipment of 73 hogs by C. L., Dixon County. Tuberculosis in 10 animals. Lesions in cervical lymphnodes only. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A moderate degree of tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 5026. A shipment of 66 hogs by P. D., Wayne County. Tuberculosis in 17 animals. Lesions in cervical lymphnodes in 10 and in mesenteric lymphnodes in 7. Bacilli were present in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

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No. 5027. A shipment of 69 hogs by E. C. A., Holt County. Tuberculosis in 16 animals. Lesions in cervical lymphnodes in 14 and in mesenteric lymphnodes in 2. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A moderate degree of tuberculosis in both fowls. Lesions in livers and spleens. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 5028. A shipment of 75 hogs by G. F., Wayne County. Tuberculosis in 15 animals. Lesions in cervical lymphnodes in 13 and in mesenteric lymphnodes in 2. Bacilli were present in moderate numbers in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Extensive, generalized, progressive tuberculosis in both cavias. Bacilli were present in the lesions.	Marked tuberculosis of both fowls. Lesions in livers and spleens. Bacilli were found to be present in the lesions.

Classification of infection type = Mixed.

No. 5029. A shipment of 61 hogs by W. B., Cedar County. Tuberculosis of 12 animals. Lesions in cervical lymphnodes only. Bacilli were numerous in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Very extensive tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 5030. A shipment of 72 hogs by F. S., Cedar County. Tuberculosis in 6 animals. Lesions in cervical lymphnodes in 2 and in mesenteric lymphnodes in 4. Bacilli were present in the lesions but very scarce.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

No. 5031. A shipment of 61 hogs by F. W., Wayne County. Tuberculosis in 5 animals. Lesions of cervical lymphnodes only. Bacilli were present in moderate numbers in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis of livers and spleens of both fowls, with bacilli numerous in the lesions.

Classification of infection type = Avian.

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No. 5032. A shipment of 65 hogs by S. K. L., Knox County. Tuberculosis in 4 animals. Lesions in cervical lymphnodes only. Bacilli were present in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Slight tuberculosis in liver and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 5033. A shipment of 44 hogs by L. A., Wayne County. Tuberculosis of 2 animals. Lesions in cervical lymphnodes only. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis of livers and spleens of both fowls. Bacilli were numerous in the lesions.

Classification of infection type = Avian.

No. 5034. A shipment of 56 hogs by W. T., Wayne County. Tuberculosis in 2 animals. Lesions in cervical lymphnodes only. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked or extensive tuberculosis in all 3 fowls. Lesions in livers and spleens in which bacilli were found to be present.

Classification of infection type = Avian.

No. 5035. A shipment of 60 hogs by C. J. D., Dakota County. Tuberculosis in one animal. Lesions in cervical lymphnodes only. This material was so unpromising that it was discarded.

No. 5052. Tuberculous material obtained from a shipment of 127 hogs by B. S., Richardson County. Bacilli were present in this material in moderate numbers.

INOCULATION RESULTS

Cavias	*Fowls*
Both cavias developed a non-progressive, localized type of tuberculosis. Bacilli were present in the lesions. The cavias were killed in 3 months after inoculation and were at that time quite fat and in excellent physical condition.	A moderate or slight degree of tuberculosis in both fowls. Lesions in livers and spleens in which bacilli were found to be present.

Classification of infection type = Mixed.

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No. 5094. Tuberculous material obtained from a shipment of 62 hogs by J. S., Saline County. Bacilli were very numerous in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis of the liver and spleen of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 5095. A shipment of 64 hogs by J. L. L., Antelope County. Tuberculosis in 5 animals. Lesions in cervical lymphnodes only. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked or extensive tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 5096. A shipment of 54 hogs by J. R., Pierce County. Tuberculosis in 4 animals. Lesions in cervical lymphnodes in 3 and in mesenteric lymphnodes in one. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Both cavias, when killed, showed a number of small abscesses of the spleen, which were probably of tuberculous origin since in one organisms were found which to all appearances were poorly stained tubercle bacilli.	Very extensive tuberculosis of livers and spleens of both fowls. Bacilli were very numerous in the lesions.

Classification of infection type = Avian.

No. 5097. A shipment of 75 hogs by J. F., Knox County. Tuberculosis in 8 animals. Lesions in cervical lymphnodes in 7 and in mesenteric lymphnodes in one. Bacilli were present in the material in moderate numbers.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	One died prematurely without showing evidence of tuberculosis. The other showed one small tuberculous nodule in the spleen in which a few bacilli could be found.

Classification of infection type = Probably Avian.

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No. 5098. A shipment of 62 hogs by H. A. P., Cedar County. Tuberculosis in 8 animals. Lesions in cervical lymphnodes in 6 and in mesenteric lymphnodes in 2. Bacilli were present in the lesions in moderate numbers.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis in both fowls. Lesions in livers and spleens in which bacilli were numerous.

Classification of infection type = Avian.

No. 5099. A shipment of 47 hogs by W. S., Dixon County. Tuberculosis in 8 animals. Lesions in cervical lymphnodes in 5 and in mesenteric lymphnodes in 3. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of livers and spleens of both fowls with bacilli present in the lesions.

Classification of infection type = Avian.

No. 5100. A shipment of 71 hogs by R. N., Pierce County. Tuberculosis in 12 animals. Lesions in cervical lymphnodes only. Bacilli were present in the material.

INOCULATION RESULTS

Cavias	*Fowls*
One cavia died with very extensive, generalized, progressive tuberculosis. Bacilli were numerous in the lesions. The other cavia, killed, in an extremely emaciated condition, revealed not the slightest evidence of tuberculosis.	Negative

Classification of infection type = Mammalian.

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No. 5102. A shipment of hogs by G. S., Knox County. Tuberculosis in 12 animals. Lesions in cervical lymphnodes in 6 and in mesenteric lymphnodes in 6. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 5103. A shipment of 67 hogs by J. R., Knox County. Tuberculosis in 14 animals. Lesions in cervical lymphnodes only. Bacilli were present in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive or marked tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 5104. A shipment of 22 hogs by W. B., Thurston County. Tuberculosis in 14 animals. Lesions in cervical lymphnodes only. Bacilli were numerous in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis in both fowls. Lesions in livers and spleens in which bacilli were plentiful.

Classification of infection type = Avian.

No. 5120. Tuberculous lymphnodes obtained from a shipment of 64 hogs by L. D. C., Hitchcock County. Bacilli were scarce in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of livers and spleens of both fowls. Bacilli were found to be present in the lesions.

Classification of infection type = Avian.

No. 5140. A shipment of 33 hogs by W. V., Dakota County. Tuberculosis in 6 animals. Lesions in cervical lymphnodes in 5 and in mesenteric lymphnodes in one. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked or extensive tuberculosis of livers and spleens of both fowls. Bacilli were numerous in the lesions.

Classification of infection type = Avian.

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No. 5141. A shipment of 62 hogs by R. G. R., Antelope County. Tuberculosis in 2 animals. Lesions in cervical lymphnodes in one and in the mesenteric lymphnodes in one.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A moderate degree of tuberculosis of both fowls. Lesions in livers and spleens in which bacilli were present.

Classification of infection type=Avian.

No. 5142. A shipment of 68 hogs by P. J. B., Pierce County. Tuberculosis in 7 animals. Lesions in cervical lymphnodes in 4 and in mesenteric lymphnodes in 3. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type=Avian.

No. 5143. A shipment of 77 hogs by A. O., Cedar County. Tuberculosis in 11 animals. Lesions in cervical lymphnodes in 9 and in mesenteric lymphnodes in 2. Bacilli were found to be numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis in both fowls. Lesions in livers and spleens in which bacilli could be found to be present.

Classification of infection type=Avian.

No. 5167. A shipment of 49 hogs by K. E., Cedar County. Tuberculosis in 9 animals. Lesions in cervical lymphnodes in 7 and in mesenteric lymphnodes in 2. Bacilli were found to be present in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis in both fowls. Lesions in livers and spleens in which bacilli were present.

Classification of infection type=Avian.

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No. 5169. A shipment of 65 hogs by L. K., Knox County. Tuberculosis in 4 animals. Lesions in cervical lymphnodes in 2 and in mesenteric lymphnodes in 2. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Very extensive tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 5170. A shipment of 65 hogs by E. A. K., Pierce County. Tuberculosis in 3 animals. Lesions in cervical lymphnodes in 2 and in mesenteric lymphnodes in one. Bacilli were present in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis in both fowls. Lesions in livers and spleens in which bacilli were present.

Classification of infection type = Avian.

No. 5182. A shipment of 66 hogs by H. B. Z., Buffalo County. Tuberculosis in 9 animals. Slight cervical lesions only, in which bacilli were present.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A marked or moderate degree of tuberculosis in both fowls. Lesions in livers and spleens. Bacilli were present in the material.

Classification of infection type = Avian.

No. 5183. A shipment of 58 hogs by A. D., Hamilton County. Tuberculosis in 5 animals. Lesions of cervical lymphnodes in 4 and in mesenteric lymphnodes in one. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

No. 5190. A shipment of 66 hogs by F. E. Co., Platte County. Tuberculosis in 5 animals. Slight lesions in cervical lymphnodes in 2 and in mesenteric lymphnodes in 2. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Very extensive or marked tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

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No. 5191. A shipment of 65 hogs by J. C. F., Madison County. Tuberculosis in 15 animals. Lesions in cervical lymphnodes in 8 and in mesenteric lymphnodes in 7. Bacilli were very numerous in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Very extensive tuberculosis of livers and spleens of both fowls. Bacilli were to be found in the lesions.

Classification of infection type = Avian.

No. 5192. A shipment of 62 hogs by W. O., Platte County. Tuberculosis in 20 animals. Lesions in cervical lymphnodes in 14 and in mesenteric lymphnodes in 6. Bacilli were present in lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Very extensive tuberculosis of livers and spleens of both fowls. Bacilli were very numerous in the lesions.

Classification of infection type = Avian.

No. 5193. A shipment of 69 hogs by J. C. F., Madison County. Tuberculosis in 9 animals. Slight lesions in cervical lypmhnodes in 8 and in mesenteric lymphnodes in one. Bacilli were present in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A moderate degree of tuberculosis of both fowls. Lesions in livers and spleens in which bacilli were present.

Classification of infection type = Avian.

No. 5194. A shipment of 64 hogs by H. & O., Nance County. Tuberculosis in 13 animals. Lesions in cervical lymphnodes in 9 and in mesenteric lymphnodes in 4. Bacilli numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 5195. A shipment of 58 hogs by F. J. N., Antelope County. Tuberculosis in 12 animals. Lesions in cervical lymphnodes in 7 and in mesenteric lymphnodes in 5. Bacilli were numerous in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

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No. 5198. A shipment of 60 hogs by F. J. L., Boyd County. Tuberculosis in 9 animals. Lesions in cervical lymphnodes in 8 and in mesenteric lymphnodes in one. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A slight tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 5201. A shipment of 79 hogs by W. F. L., Wayne County. Mesenteric lesions only. Bacilli were very numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 5202. Tuberculous lymphnodes obtained from a shipment of 47 hogs by H. B., Cedar County. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 5203. Tuberculous lymphnodes obtained from a shipment of 73 hogs by A. S., Wayne County. Bacilli were very numerous in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis of both fowls. Lesions in livers, spleens, and intestine in which bacilli were present.

Classification of infection type = Avian.

No. 5207. A shipment of 76 hogs by G. M. R., Nance County. Tuberculosis in 12 animals. Lesions in cervical lymphnodes in 7 and mesenteric lymphnodes in 5. Bacilli were numerous in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis in both fowls, extensive lesions in livers and spleens of one fowl and slight lesions in the liver of the other one. Bacilli were present in the lesions.

Classification of infection type = Avian.

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No. 5208. A shipment of 70 hogs by A. K., Pierce County. Tuberculosis of 35 animals. Lesions in cervical lymphnodes in 12, in mesenteric lymphnodes in 11, and cervical and mesenteric lymphnodes in 2. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive and marked tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 5213. A shipment of 60 hogs by S. C., Antelope County. Tuberculosis in 6 animals. Lesions in cervical lymphnodes only. Bacilli were present in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

No. 5214. A shipment of 75 hogs by F. G., Cedar County. Tuberculosis in 15 animals. Lesions in cervical lymphnodes in 13 and in mesenteric lymphnodes in 2. Bacilli were present in this material, but very scarce.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

No. 5215. A shipment of 74 hogs by R. H., Knox County. Tuberculosis in 25 animals. Lesions in cervical lymphnodes in 15 and in mesenteric lymphnodes in 10. Bacilli were numerous in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

No. 5216. A shipment of 72 hogs by G. W. C., Greeley County. Tuberculosis in 19 animals. Lesions in cervical lymphnodes in 11 and in mesenteric lymphnodes in 8. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	One fowl showed no lesions while the other developed a marked tuberculosis of liver and spleen in the lesions of which bacilli were present.

Classification of infection type = Avian.

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No. 5219. A shipment of 56 hogs by H. K., Platte County. Tuberculosis in 8 animals. Lesions in cervical lymphnodes in 5 and in mesenteric lymphnodes in 3. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis in both fowls. Lesions in livers and spleens. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 5220. A shipment of 67 hogs by H. & L., Howard County. Tuberculosis in 8 animals. Lesions in cervical lymphnodes in 4 and in mesenteric lymphnodes in 4. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A moderate degree of tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 5224. A shipment of 78 hogs by J. V., Dodge County. Tuberculosis in 17 animals. Lesions in cervical lymphnodes in 6 and in mesenteric lymphnodes in 11. Bacilli numerous in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis of livers and spleens of both fowls. Bacilli present in the lesions.

Classification of infection type = Avian.

No. 5225. A shipment of 73 hogs by U. G. B., Burt County. Tuberculosis in 5 animals. Lesions in cervical lymphnodes only. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative with the exception of one small nodule in the liver of one in which a few bacilli could be found.	Very extensive tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions in enormous numbers.

Classification of infection type = Avian.

No. 5226. A shipment of 79 hogs by C. C., Howard County. Tuberculosis in 7 animals. Lesions in cervical lymphnodes in 6 and in mesenteric lymphnodes in 1. Bacilli were present in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Marked tuberculosis of livers, spleens, lungs, and lymphnodes of both cavias. Apparently disease was a non-progressive type. Both cavias were in good physical condition, about 11 weeks after inoculation. Bacilli were present in the lesions in moderate numbers.	Very extensive tuberculosis of livers and spleens of both fowls. Bacilli were very numerous in the lesions.

Classification of infection type = Mixed.

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No. 5227. A shipment of 60 hogs by W. W. S., Antelope County. Tuberculosis in 7 animals. Lesions in cervical lymphnodes in one and in mesenteric lymphnodes in 6. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis in both fowls. Lesions in livers, spleens, and lungs. Bacilli very numerous in the material.

Classification of infection type = Avian.

No. 5231. A shipment of 70 hogs by S. S., Fillmore County. Tuberculosis in 7 animals. Lesions in cervical lymphnodes in 5, in mesenteric lymphnodes in one, and in cervical and mesenteric lymphnodes in one. Bacilli were present in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative with the exception of caseous lymphnodes near point of inoculation.	A moderate degree of tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 5237. A shipment of 66 hogs by E. P., Pierce County. Tuberculosis in 17 animals. Lesions in cervical lymphnodes in 12, in mesenteric lymphnodes in 4, and in cervical and mesenteric lymphnodes in one. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative in one cavia, in the other very extensive tuberculosis of liver and spleen. Extensive tuberculosis of lungs and inguinal lymphnodes. Bacilli were present in the spleen but very scarce.	Very extensive tuberculosis in liver and spleens of both fowls. Bacilli were very numerous in the lesions.

Classification of infection type = Mixed.

No. 5239. A shipment of 68 hogs by K. & B., Nance County. Tu-

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No. 5255. A shipment of 45 hogs by F. E. P., Dodge County. Tuberculosis in 4 animals. Lesions in cervical lymphnodes in 2 and in mesenteric lymphnodes in 2. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Extensive tuberculosis of livers, spleens, and lungs. Marked caseation of inguinal lymphnodes. Bacilli were exceedingly scarce in the lesions.	Negative in one fowl and few small, non-progressive lesions of liver and spleen of the other. Bacilli were present in those lesions.

Classification of infection type = Mammalian.

No. 5256. A shipment of 56 hogs by H. S., Cuming County. Tuberculosis in 11 animals. Lesions in cervical lymphnodes in 6 and in mesenteric lymphnodes in 5. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative in one fowl and many tuberculous nodes in the spleen of the other. In those lesions bacilli were very numerous.

Classification of infection type = Avian.

No. 5261. A shipment of 52 hogs by G. R., Cedar County. Tuberculosis in 8 animals. Lesions in cervical lymphnodes in 6 and in mesenteric lymphnodes in 2. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of both fowls. Lesions in livers and spleens in which bacilli were present.

Classification of infection type = Avian.

No. 5262. A shipment of 26 hogs by W. K., Cedar County. Tuberculosis in 9 animals. Lesions in cervical lymphnodes in 8 and in mesenteric lymphnodes in one. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A marked tuberculosis of liver and spleen of one fowl and more moderate tuberculous lesions of the same organs in the other. Bacilli were present in all lesions.

Classification of infection type = Avian.

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No. 5264. A shipment of 53 hogs by F. S. A., Boone County. Tuberculosis in seven animals. Lesions in cervical lymphnodes in 3 and in mesenteric lymphnodes in 4. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extremely marked miliary tuberculosis of both fowls. Lesions of livers, spleens, lungs, kidneys, and peritonea. Lesions literally packed with bacilli.

Classification of infection type = Avian.

No. 5272. A shipment of 87 hogs by N. & V., Colfax County. Tuberculosis in 17 animals. Lesions in cervical lymphnodes in 5, in mesenteric lymphnodes in 7, and in cervical and mesenteric lymphnodes in 5. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Very extensive tuberculosis in livers and spleens of both fowls. Bacilli were very numerous in the lesions.

Classification of infection type = Avian.

No. 5273. A shipment of 37 hogs by J. N., Cedar County. Tuberculosis in 5 animals. Lesions in cervical lymphnodes in 3 and in mesenteric lymphnodes in 2. Bacilli were numerous in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 5281. A shipment of 90 hogs by J. D., Madison County. Tuberculosis in 11 animals. Lesions in cervical lymphnodes in 6 and in mesenteric lymphnodes in 5. Bacilli present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis of both fowls. Lesions in livers, spleens, and lungs. Bacilli were present in the lesions.

Classification of infection type = Avian.

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No. 5282. A shipment of 63 hogs by J. V., Dodge County. Tuberculosis in 16 animals. Lesions in cervical lymphnodes in 11, in mesenteric lymphnodes in 3, and in cervical and mesenteric lymphnodes in 2. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative, with the exception of caseous lesions of lymphnode near inoculation point. Bacilli were present in this material.	Extensive or marked tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 5286. A shipment of 83 hogs by P. B., Stanton County. Tuberculosis in 19 animals. Lesions in cervical lymphnodes in 18 and in mesenteric lymphnodes in one. Bacilli were found to be present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A few small nodules in the liver and spleen of one fowl and extensive tuberculosis of those organs in the other. Bacilli were present in all lesions.

Classification of infection type = Avian.

No. 5287. A shipment of 92 hogs by H. & B., Seward County. Tuberculosis in 4 animals. Lesions in cervical lymphnodes in 2 and in mesenteric lymphnodes in 2. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A few small tubercles in the livers and spleens of both fowls. In only one of the spleens could bacilli be found.

Classification of infection type = Avian.

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No. 5292. A shipment of 69 hogs by H. & S., Buffalo County. Tuberculosis in 5 animals. Lesions only in cervical lymphnodes. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type=Avian.

No. 5296. A shipment of 36 hogs by L. E. P., Madison County. Tuberculosis in 7 animals. Lesions in cervical lymphnodes in 6 and in mesenteric lymphnodes in one. Bacilli were present in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A moderate degree of tuberculosis of both fowls. Lesions in livers and spleens in which bacilli were present.

Classification of infection type=Avian.

No. 5297. A shipment of 48 hogs by J. W. C., Boone County. Tuberculosis in 22 animals. Lesions in cervical lymphnodes in 20 and in mesenteric lymphnodes in 2. Bacilli were present in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A moderate degree of tuberculosis of both fowls. Lesions in livers and spleens. Bacilli were present in the lesions.

Classification of infection type=Avian.

No. 5298. A shipment of 52 hogs by A. S., Pierce County. Tuberculosis in 3 animals. Lesions in cervical lymphnodes in one, in mesenteric lymphnodes in one, and in portal lymphnodes in one. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extremely marked acute miliary tuberculosis of livers and spleens of both fowls. Bacilli were numerous in the material.

Classification of infection type=Avian.

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No. 5308. A shipment of 56 hogs by O. P., Cuming County. Tuberculosis in 28 animals. Lesions in cervical lymphnodes in 18, in mesenteric lymphnodes in 8, and in cervical and mesenteric lymphnodes in 2. Bacilli were very numerous in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of livers and spleens of both fowls. Bacilli were numerous in the lesions.

Classification of infection type = Avian.

No. 5311. A shipment of 49 hogs by A. R., Dodge County. Tuberculosis in 9 animals. Lesions in cervical lymphnodes only. Bacilli were present in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis of both fowls. Lesions in livers and spleens. Bacilli were numerous in the lesions.

Classification of infection type = Avian.

No. 5312. A shipment of 28 hogs by R. E. G., Cedar County. Tuberculosis in 2 animals. Lesions in cervical lymphnodes in one and in mesenteric lymphnodes in one. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Negative

Classification of infection type = Undetermined.

No. 5313. A shipment of 38 hogs by W. R., Knox County. Tuberculosis in 3 animals. Lesions in cervical lymphnodes in 2 and in mesenteric lymphnodes in one. Bacilli were present in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of livers and spleens of both fowls. Bacilli were numerous in the lesions.

Classification of infection type = Avian.

No. 5316. A shipment of 65 hogs by R. H. S., Antelope County. Tuberculosis in 9 animals. Lesions in cervical lymphnodes in 8 and in mesenteric lymphnodes in one. Bacilli were present in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Extensive tuberculosis of livers and spleens of both fowls. Bacilli were numerous in the lesions.

Classification of infection type = Avian.

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No. 5317. A shipment of 52 hogs by J. P., Knox County. Tuberculosis in 12 animals. Lesions in cervical lymphnodes in 11 and in cervical and mesenteric lymphnodes in one. Bacilli were present in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A slight degree of tuberculosis of the livers of both fowls. Bacilli were present in the material.

Classification of infection type = Avian.

No. 5318. A shipment of 57 hogs by C. K., Cedar County. Tuberculosis in 9 animals. Lesions in cervical lymphnodes in 8 and in mesenteric lymphnodes in one. Bacilli were to be found in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 5319. Two shipments of 53 and 51 hogs by H. W. H., Cedar County. Tuberculosis in 27 animals. Lesions in cervical lymphnodes in 24 and in mesenteric lymphnodes in 3. Bacilli were present in this material.

INOCULATION RESULTS

Cavias	*Fowls*
Marked tuberculosis of livers, spleens and lymphnodes of both cavias. Appearance of lesions indicate a non-progressive type of disease. Bacilli were present in the lesions.	Negative

Classification of infection type = Mammalian.

No. 5320. A shipment of 59 hogs by H. C. H., Knox County. Tuberculosis in 4 animals. Lesions in cervical lymphnodes only. Bacilli present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of livers and spleens of both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 5321. A shipment of 42 hogs by G. J., Dixon County. Tu-

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No. 5322. A shipment of 71 hogs by S. S., Wayne County. Tuberculosis in 26 animals. Lesions in cervical lymphnodes in 14 and in mesenteric lymphnodes in 12. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Tuberculosis of livers and spleens of both fowls. Bacilli were numerous in the lesions.

Classification of infection type = Avian.

SUMMARY OF RESULTS

From the details recorded above it will be observed that in the inquiry, material obtained from 250 Nebraska shipments of swine[1] originating in 41 counties was used. Those shipments represented a total of more than 14,299 swine of which not less than 2,781 or 19.5 per cent were retained on account of tuberculosis.

Of the 250 lymphnode consignments 2 were discarded, 31 gave negative results (Group I) and 8 yielded results which made avian origin of the infection highly probable (Group IV). The number of consignments which yielded results permitting a definite interpretation thus was 209.

The results obtained with this number are as follows:

Infection Type	No.	Per cent
Mammalian (Group II)	11	5.21
Avian (Group III)	185	88.51
Mixed (Group V)	13	6.22
Total	209	99.94

FIELD SURVEY

In the original schedule of the inquiry provision was made for a survey on the farms on which the shipments of tuberculous swine originated with a view of ascertaining the presence of tuberculosis among the cattle and poultry from which the swine might have contracted their infection. This part of the investigation was regarded as a valuable control of such laboratory results as may be obtained and as a means of either strengthening the final conclusions or of revealing whatever unknown factor of error might enter in the solution of the problem.

[1] Including one shipment from So. Dakota.

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The inspector in charge of the field force of the U. S. Bureau of Animal Industry, operating in the state in connection with the co-operative tuberculosis eradication campaign, was appealed to for assistance and he undertook to make the surveys required so far as this could be done in conjunction with the work in hand.

Unfortunately, the withdrawal of a part of the available inspectors for urgent duties in other states necessitated the abandonment of the surveys shortly after they were begun.

A small number of surveys were, however, completed and their results coincided with those of the inoculation tests to such an extent that they materially contributed to the success of the investigation. As those surveys were made during the earlier phase of the inquiry they likewise inspired confidence in the method adopted in its pursuit.

The surveys were made with thoroness on the part of the inspectors, and with the consent of the owners, tuberculin tests were made of the cattle and poultry present on the farms, while in a number of cases swine were also included in the field investigation.

When some tuberculous swine originated from the farms concerned, the testing of those not shipped was not an urgent matter. However, by using in the testing an avian tuberculin as well as a mammalian tuberculin simultaneously, a different tuberculin on each ear of the animals tested, an interesting side light on the diagnosis of swine tuberculosis was obtained as some of the following data will show:

No. 3188. Infection type determined by inoculation = Avian.

FIELD SURVEY RESULTS

Cattle tested 23	Reactors 0.
Swine tested 12	Reactors 2.
Chickens tested 20	Reactors 9.

In testing the swine use was made of both avian and mammalian tu-

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No. 3266. Infection type determined by inoculation = Avian.

FIELD SURVEY RESULTS

Cattle tested 85.....Reactors 0.
Swine tested 58.....Reactors 0.
Chickens tested 407.....Reactors 19.

The diagnosis of tuberculosis of poultry was confirmed by autopsy.

No. 3499. Infection type determined by inoculation = Avian.

This shipment was composed of swine originating from three farms. Here follow the survey results for each:

No. 1

Cattle tested 3.....Reactors 0.
Swine tested 11.....Reactors 0.
Chickens tested 46.....Reactors 0.

No. 2

Cattle tested 19.....Reactors 0.
Swine tested 11.....Reactors 0.
Chickens tested 86.....Reactors 0.

No. 3

Cattle tested 12.....Reactors 0.
Swine tested 17.....Reactors 8.
Chickens tested 77.....Reactors 20.

The swine were tested with both avian and mammalian tuberculin. They reacted only to the avian tuberculin. The diagnosis of tuberculosis of the poultry was confirmed by autopsy.

No. 3500. Infection type determined by inoculation = Avian.

FIELD SURVEY RESULTS

Cattle tested 15.....Reactors 0.
Swine tested 31.....Reactors 0.
Chickens tested 89.....Reactors 4.

The reacting fowls were examined by autopsy and found to be tuberculous.

No. 3611. Infection type determined by inoculation = Avian.

FIELD SURVEY RESULTS

Cattle tested 18.....Reactors 0.
Swine tested 5.....Reactors 4.

Fowls were not tested on this farm but the existence of tuberculosis among the poultry was determined by autopsy.

No. 3612. Infection type determined by inoculation = Avian.

FIELD SURVEY RESULTS

Cattle tested 11.....Reactors 0.
Swine tested 7.....Reactors 5.
Chickens tested 124.....Reactors 26.

The swine were tested with both avian and mammalian tuberculin. In no case were reactors obtained with the mammalian tuberculin. Diagnosis of tuberculosis in poultry confirmed by autopsy.

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No. 3613. Infection type determined by inoculation = Avian.

FIELD SURVEY RESULTS

Cattle tested 11.....Reactors 0.
Chickens tested 40.....Reactors 7.

The diagnosis of tuberculosis in the chickens was confirmed by autopsy.

No. 3614. Infection type determined by inoculation = Avian.

FIELD SURVEY RESULTS

Cattle tested 8.....Reactors 0.
Swine tested 6.....Reactors 0.
Chickens tested 32.....Reactors 13.

The diagnosis of tuberculosis in the poultry flock was confirmed by autopsy.

No. 3615. Infection type determined by inoculation = Avian.

FIELD SURVEY RESULTS

Cattle tested 3.....Reactors 0.
Chickens tested 20.....Reactors 4.

Autopsies of the 4 reacting fowls confirmed the tuberculin test results.

No. 3617. Infection type determined by inoculation = Avian.

FIELD SURVEY RESULTS

Evidence of the existence of poultry tuberculosis was discovered on this farm, but no definite proof of this was secured.

No. 3618. Infection type determined by inoculation = Avian.

FIELD SURVEY RESULTS

Cattle tested 9.....Reactors 0.
Swine tested 5.....Reactors 0.
Chickens tested 66.....Reactors 14.

The diagnosis of tuberculosis in the poultry flock was confirmed by autopsy.

No. 3629. Infection type determined by inoculation = Probably Avian.

FIELD SURVEY RESULTS

Cattle tested 10.....Reactors 0.
Chickens tested 50.....Reactors 23.

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No. 3732. Infection type determined by inoculation = Avian.

FIELD SURVEY RESULTS

Cattle tested 10.....Reactors 4.
Swine tested 36.....Reactors 7.
Chickens tested 13.....Reactors 4.

The swine were tested with both avian and mammalian tuberculin. Four of the reactors only reacted to the avian tuberculin.

The diagnosis of tuberculosis in the poultry flock was confirmed by autopsy.

No. 4032. Infection type determined by inoculation = Avian.

FIELD SURVEY RESULTS

Cattle tested 4.....Reactors 0.
Swine tested 3.....Reactors 3.
Chickens tested 150.....Reactors 10.

In the testing of the swine both avian and mammalian tuberculin were used. The bovine tuberculin resulted in a slight reaction in one, but the other two reacted to the avian tuberculin only.

At a later period all the swine on this farm were tuberculin tested, showing 11 reactors in the 52 swine tested. All reactions were caused by the avian tuberculin and none by the mammalian tuberculin.

No. 4388. Infection type determined by inoculation = Avian.

FIELD SURVEY RESULTS

Information by owner that his cattle had been tuberculin tested locally, without positive reactions, but that he suspected his chickens to be tuberculous.

No. 4565. Infection type determined by inoculation = Mammalian.

FIELD SURVEY RESULTS

Cattle tested 4.....Reactors 2.
Swine tested 65.....Reactors 54.
Chickens tested 88.....Reactors 0.
Turkeys tested 4.....Reactors 0.
Cats tested .....Reactors 0.

Both avian and mammalian tuberculin were used in the testing of the swine. All reactions were constant against the mammalian tuberculin and only a part of the swine reacted to the avian tuberculin also.

It will be observed that 18 field surveys were made of which 16 were complete and of value in comparing their results with those obtained in the laboratory.

The results of this comparison are summarized in Table 3. They show a practically perfect agreement in the indications furnished by the surveys and those yielded by the inoculation tests. They scarcely leave any doubt in regard to the trustworthiness of information secured thru the simul-

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TABLE 3

Findings by inoculation tests and surveys on farms	Types of tuberculosis found by inoculation and tuberculous animals found by surveys for the following shipments															
	3188	3189	3266	3499	3500	3611	3612	3613	3614	3615	3618	3629	3701	3732	4032	4565
Surveys revealing tuberculosis in cattle only	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	+
Surveys revealing tuberculosis in poultry only	+	+	+	+	+	+	+	+	+	+	+	+	+	—	+	—
Surveys revealing tuberculosis in both cattle and poultry	—	—	—	—	—	—	—	—	—	—	—	—	—	+	—	—
Mammalian type of tuberculosis shown by inoculation	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	+
Avian type of tuberculosis shown by inoculation	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	—
Mixed type of tuberculosis shown by inoculation	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

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taneous use of cavias and fowls in the typing of the tubercle bacilli found in swine.

The fact that in those cases where swine could be tested, positive reactions were more constant to avian than to mammalian tuberculin, is also pregnant with interest. While this detail lies somewhat outside the field and object of this inquiry, there are practical reasons for its consideration.

THE TYPING OF THE BACILLI ASSOCIATED WITH TUBERCULOUS LYMPHNODES OF SWINE ORIGINATING IN HILLSDALE COUNTY, MICHIGAN

Shortly after the first results of the inquiry regarding the origin of tuberculosis among Nebraska swine became available, this department was made acquainted with the fact that swine originating in the bovine tuberculosis accredited area of Hillsdale County, Michigan, furnished upon slaughter many retentions on account of tuberculosis.

Thru the courtesy of Mr. H. R. Smith, Livestock Commissioner, National Livestock Exchange, and of Dr. P. B. Wende, Inspector in Charge, Buffalo, N. Y., the tuberculous lymphnodes of 14 consignments of Hillsdale County swine were secured and used in inoculation tests similar to those undertaken with Nebraska material.

The following are the results obtained in the examination of each lot of lymphnodes:

No. 4359. Tuberculous lymphnodes of 5 hogs originating in Hillsdale County, Michigan and shipped to Buffalo, N. Y., collected 12-18-23. Bacilli were plentiful in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	One of the fowls failed to present any evidence of tuberculosis when examined by autopsy 3 months after inoculation, while the other presented a moderate number of tuberculous nodules in the liver and spleen. Bacilli were rather numerous in the lesions.

Classification of infection type = Avian.

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No. 4363. Tuberculous lymphnodes of 7 hogs originating from accredited area (Hillsdale County, Michigan) and shipped to Buffalo, N. Y. Collected 12-19-23. Establishment 383. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Developed rather extensive tuberculosis. Bacilli very scarce in the material.	The autopsy of both fowls killed 3 months after inoculation revealed slight tuberculous lesions in spleen and liver in which bacilli were extremely scarce.

Classification of infection type = Mammalian and avian mixed.

As it seemed advisable to ascertain the type of mammalian infection, its determination was undertaken by inoculation with material from one of the cavias into cavias, rabbits, and fowls. Here follow the results:

Cavias	*Rabbits*	*Fowls*
Tuberculosis; generalized, extensive, and progressive.	Tuberculosis; generalized, extensive, and progressive.	Negative

Note: The results indicate that in the passage thru the cavia of the original material the avian infection was entirely eliminated.

Final classification of infection type = Bovine and avian mixed.

No. 4384. Tuberculous lymphnodes of swine originating in Hillsdale County, Michigan. One node was taken from each hog. Bacilli were numerous in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Both fowls developed tuberculosis of liver and spleen. In one, bacilli were numerous in the lesions and in the other they were present in more moderate numbers.

Classification of infection type = Avian.

No. 4397. Tuberculous lymphnodes of swine originating in Hills-

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ciation or by W. H. Croose, Hillsdale County, Michigan. Bacilli were plentiful in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Both fowls developed a moderate degree of tuberculosis of liver and spleen. Bacilli numerous in all lesions.

Classification of infection type = Avian.

No. 4410. Tuberculous lymphnodes of swine shipped by Rowe and Adams, Camden, Michigan. Bacilli were present in the material in moderate numbers.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Both fowls developed an extensive tuberculosis of liver and spleen. In the lesions of one, bacilli were present in moderate numbers and in those of the other they were numerous.

Classification of infection type = Avian.

No. 4411. Tuberculous lymphnodes of swine shipped by Osseo Co-operative Association, Osseo, Michigan. Bacilli were present in the material in moderate numbers.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A moderate degree of tuberculosis of liver and spleen developed in both fowls. Bacilli were present in the lesions.

Classification of infection type = Avian.

No. 4439. Tuberculous lymphnodes obtained from 290 certified hogs slaughtered at Buffalo, New York, and pertaining to the following shipments:

74 hogs by Richfield Co-operative Shippers Association, Richfield, Michigan.

84 hogs by Pittsford Co-operative Association, Pittsford, Michigan.

132 hogs by Reading Co-operative Commerce Company, Reading, Michigan.

53 head retained, slaughtered 1-14-24.

Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Both fowls developed extensive tuberculosis of liver and spleen. Bacilli were numerous in the lesions.

Classification of infection type = Avian.

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No. 4443. Tuberculous lymphnodes from several retained hogs from a lot of 118 swine originating in accredited area of Hillsdale County, Michigan. Shipped by Prattville Co-operative Association. Slaughtered at Buffalo, New York, 1-12-24. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Both fowls presented an extensive tuberculosis of liver and spleen and isolated nodules in the lungs. Bacilli were numerous in the material.

Classification of infection type = Avian.

No. 4444. Tuberculous lymphnodes of several retained swine of a lot of 182 hogs originating in accredited area in Hillsdale County, Michigan. Shipped by Associated Farmers Co., Jonesville. Michigan. Slaughtered, Buffalo, New York, 1-12-24. Bacilli were present in the lesions.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Both fowls developed tuberculosis of liver and spleen. Bacilli were numerous in the lesions.

Classification of infection type = Avian.

No. 4447. Tuberculous lymphnodes of several hogs from a lot of 240 swine shipped from Hillsdale County, Michigan, by the Reading Co-operative Commerce Co. Slaughtered, Buffalo, New York, 1-16-24. The material contained bacilli in moderate numbers.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Marked tuberculosis of livers and spleens of both fowls. Bacilli were numerous in the lesions.

Classification of infection type = Avian.

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Michigan. Killed, Buffalo, New York, 1-9-24. Bacilli were present in the lesions in moderate numbers.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	A very extensive tuberculosis of livers and spleens developed in both fowls. The lesions contained many bacilli.

Classification of infection type = Avian.

No. 4471. Tuberculous lymphnodes of 99 retained swine from a lot of 553 hogs originating in Hillsdale County, Michigan. Slaughtered, Buffalo, New York, 1-21-24. Bacilli were numerous in the material.

INOCULATION RESULTS

Cavias	*Fowls*
Negative	Both fowls developed a marked tuberculosis of livers and spleens. Bacilli were numerous in all lesions.

Classification of infection type = Avian.

In the Hillsdale County series 14 consignments of tuberculous lymphnodes of swine were thus examined. In 13 of this number bacilli of the avian type only could be demonstrated. In the remaining consignment avian bacilli were also present, but they occurred in association with bacilli of the bovine type.

CONCLUSIONS

1. The type of swine tuberculosis which is responsible for the increased retentions of carcasses and the condemnation of parts is for the greater part due to infection of avian origin.

2. In the eradication and control of swine tuberculosis success can only then be attained when the two chief fountain heads of infection, namely, the tuberculous cattle herd and the tuberculous poultry flock be regarded as equally important.

3. There are indications that the steady increase in the incidence of swine tuberculosis as shown by abattoir statistics reflects a similar increase in the spread of avian tuberculosis in a large area of the United States.

4. In the intradermal tuberculin test of swine in which a mammalian tuberculin is used a considerable number of cases

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of tuberculosis will escape detection. For dependable results, avian tuberculin must also be used.

5. In the bacteriologic diagnosis of tuberculosis of swine by animal inoculation tests, the results will, for a large proportion of the cases, remain inconclusive when only cavias are used for the purpose. In the case of swine, at least, some laboratory animals susceptible to avian tuberculosis also or susceptible to both avian and mammalian tuberculosis should be included in the experiment.

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PLATES

Liver Lesions Produced in Chickens Inoculated with Tuberculous Material from Hogs Used in the Experiment.

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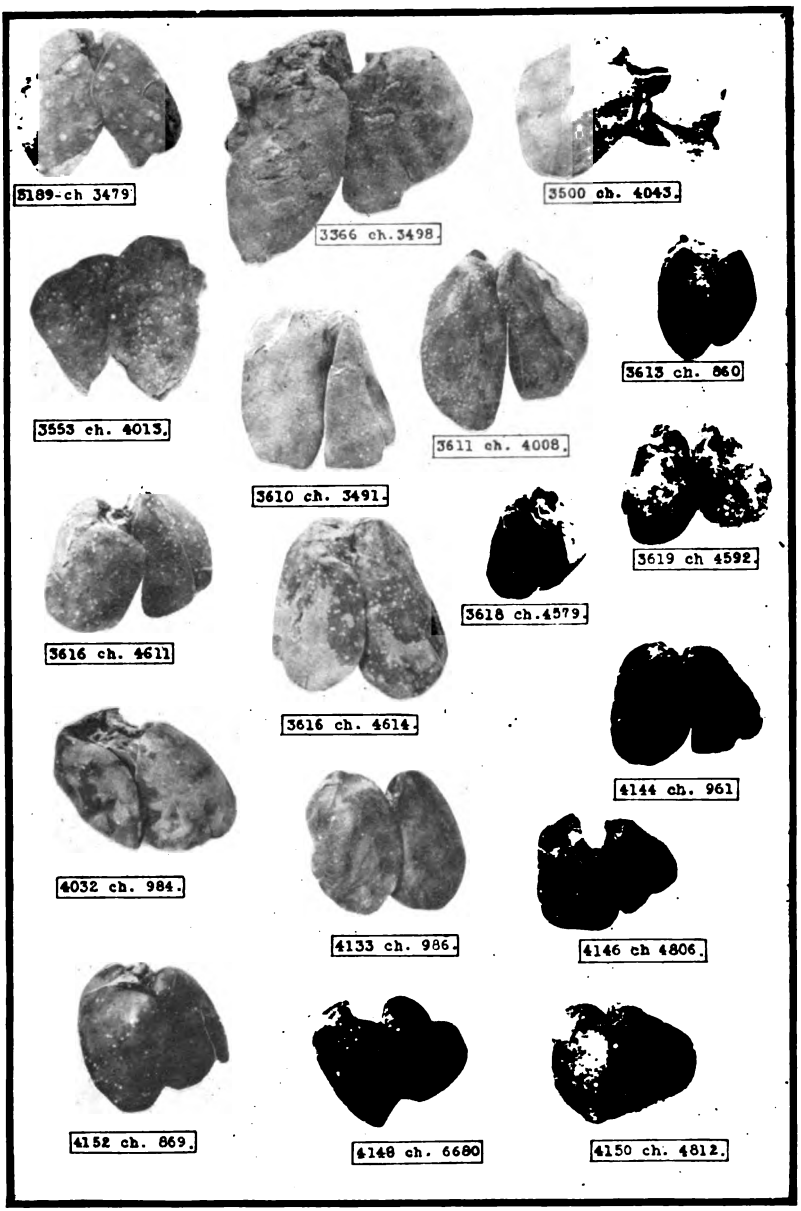

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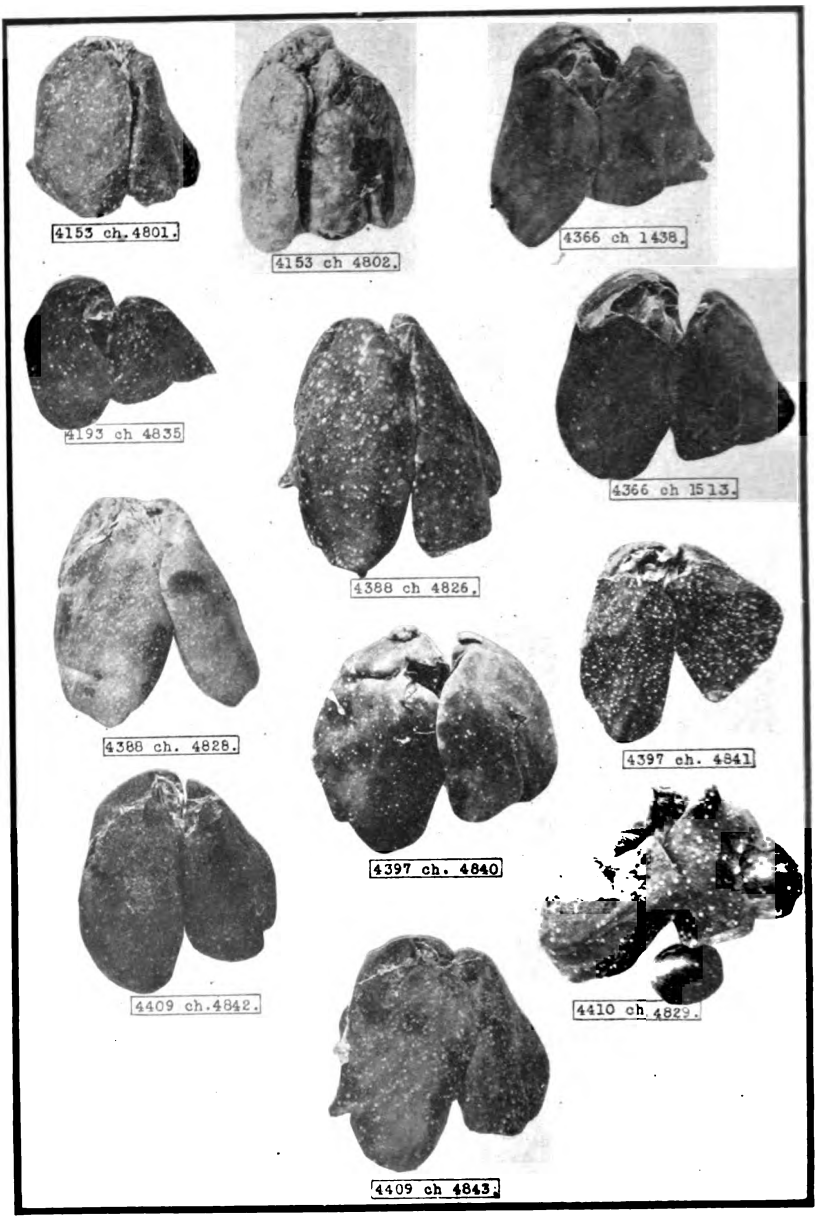

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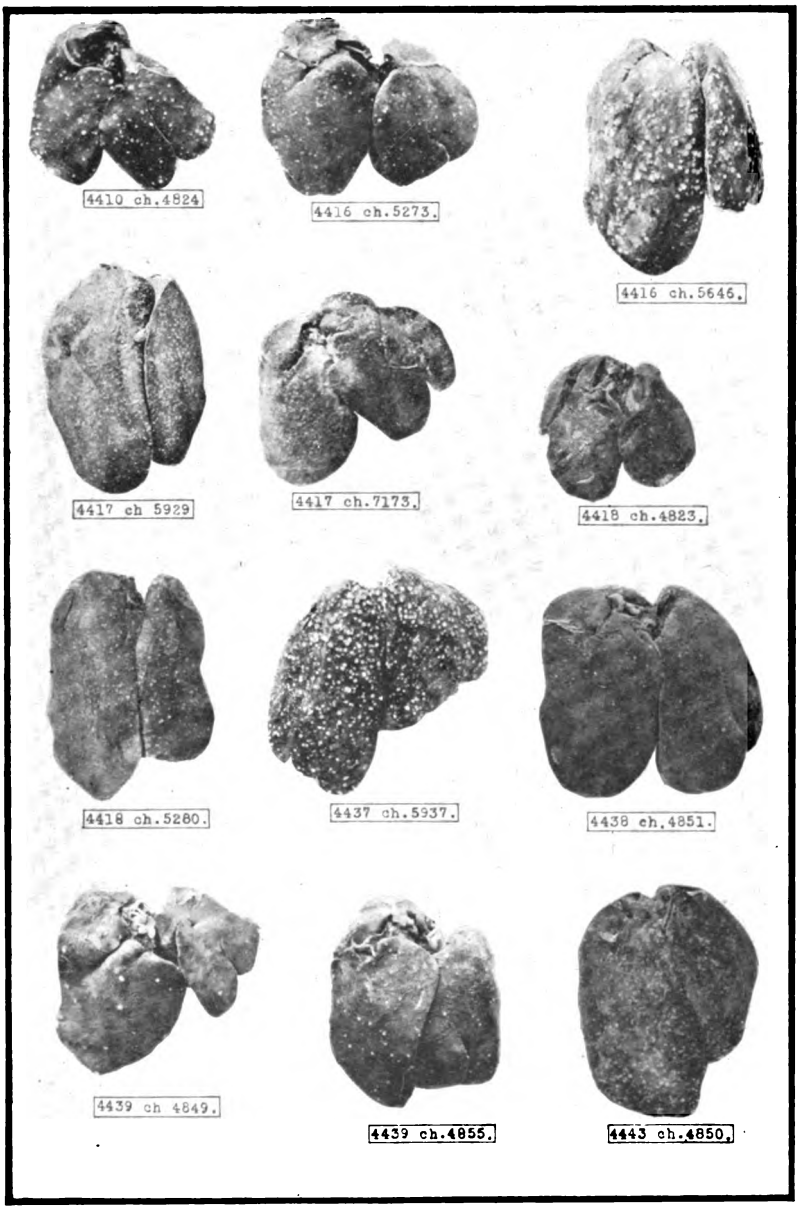

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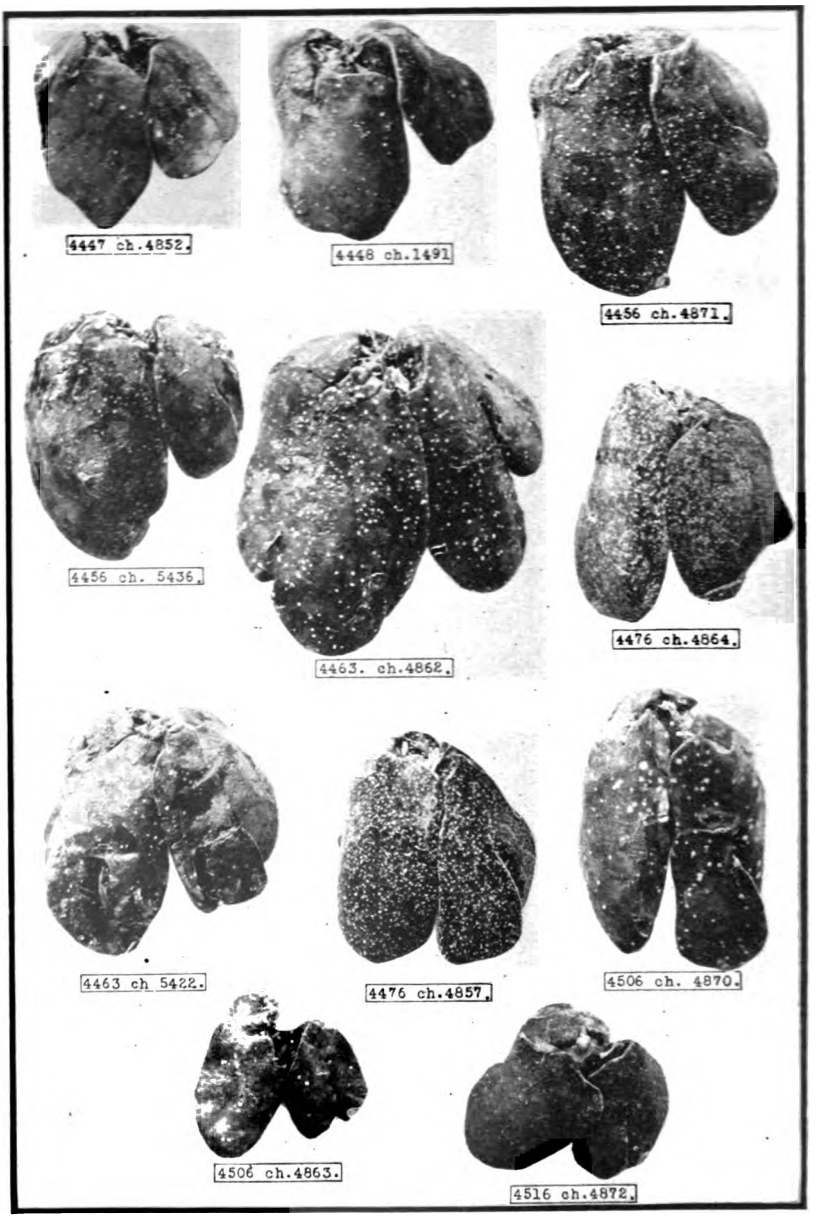

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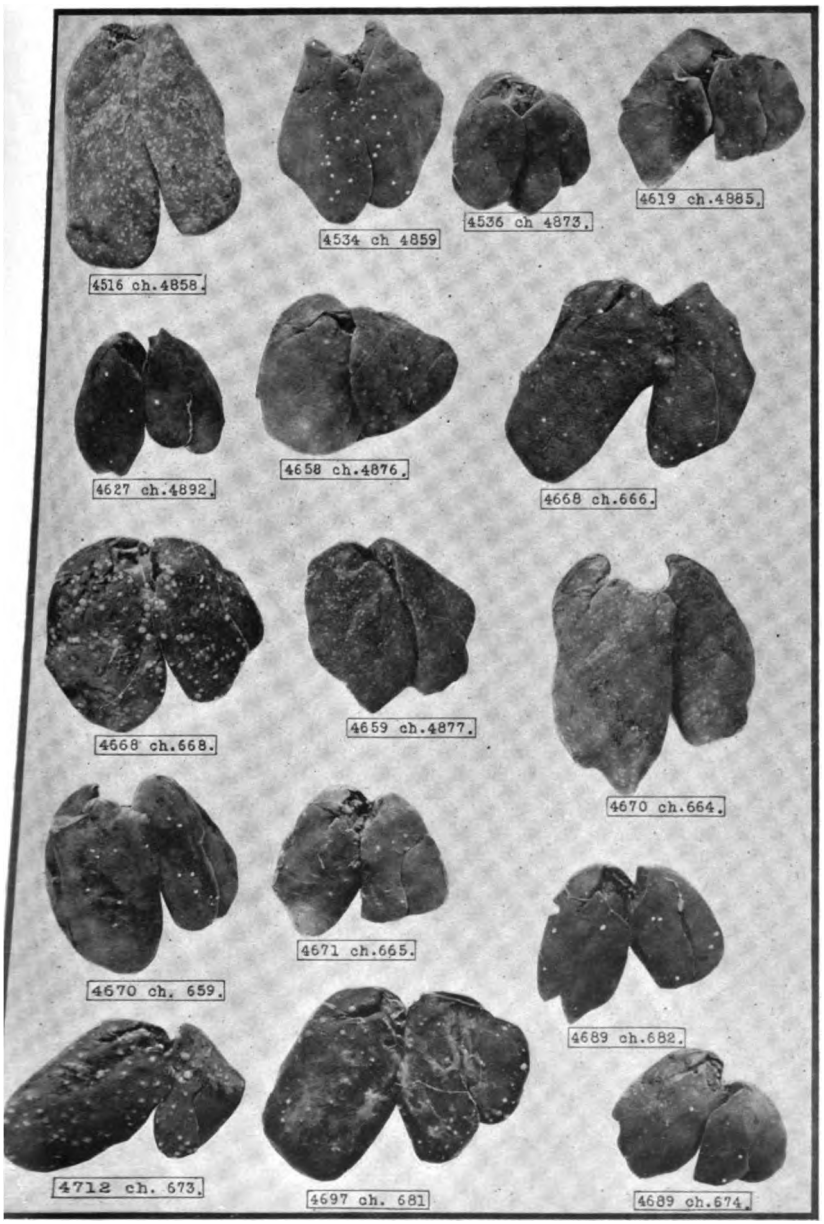

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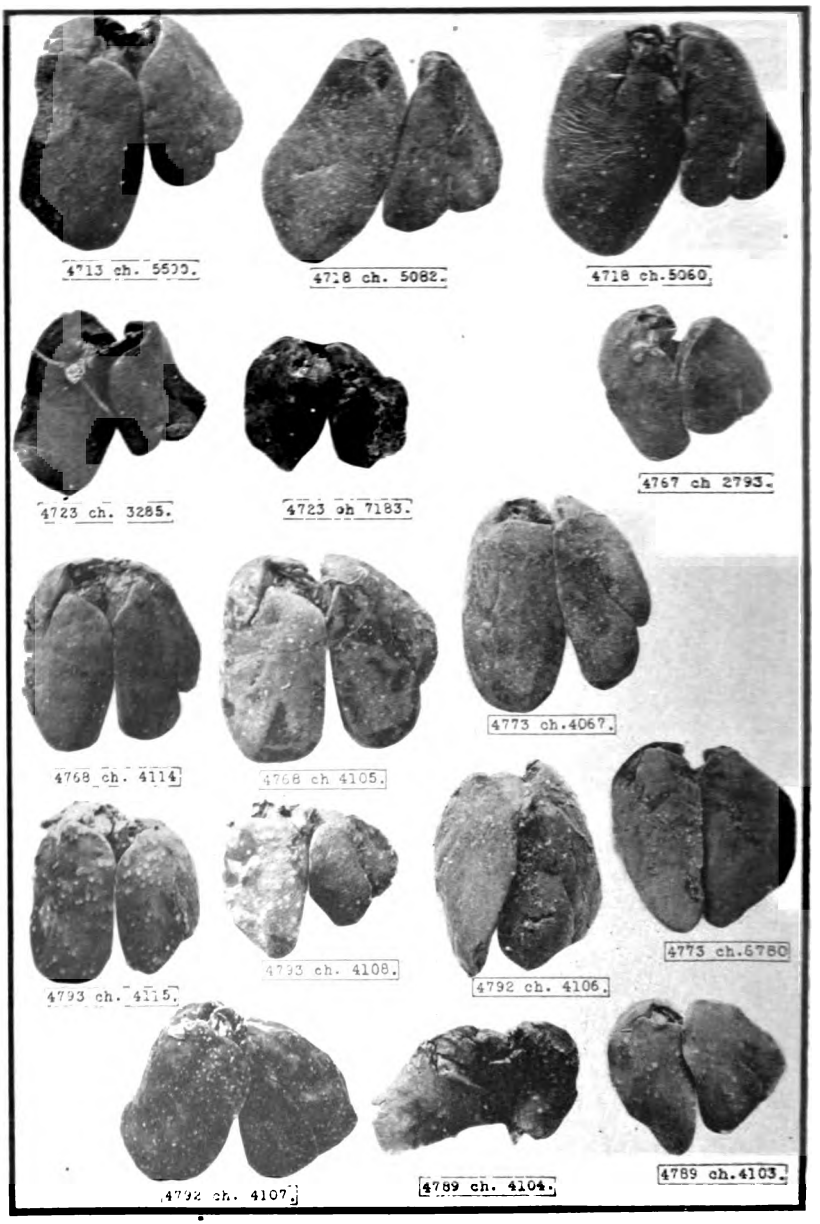

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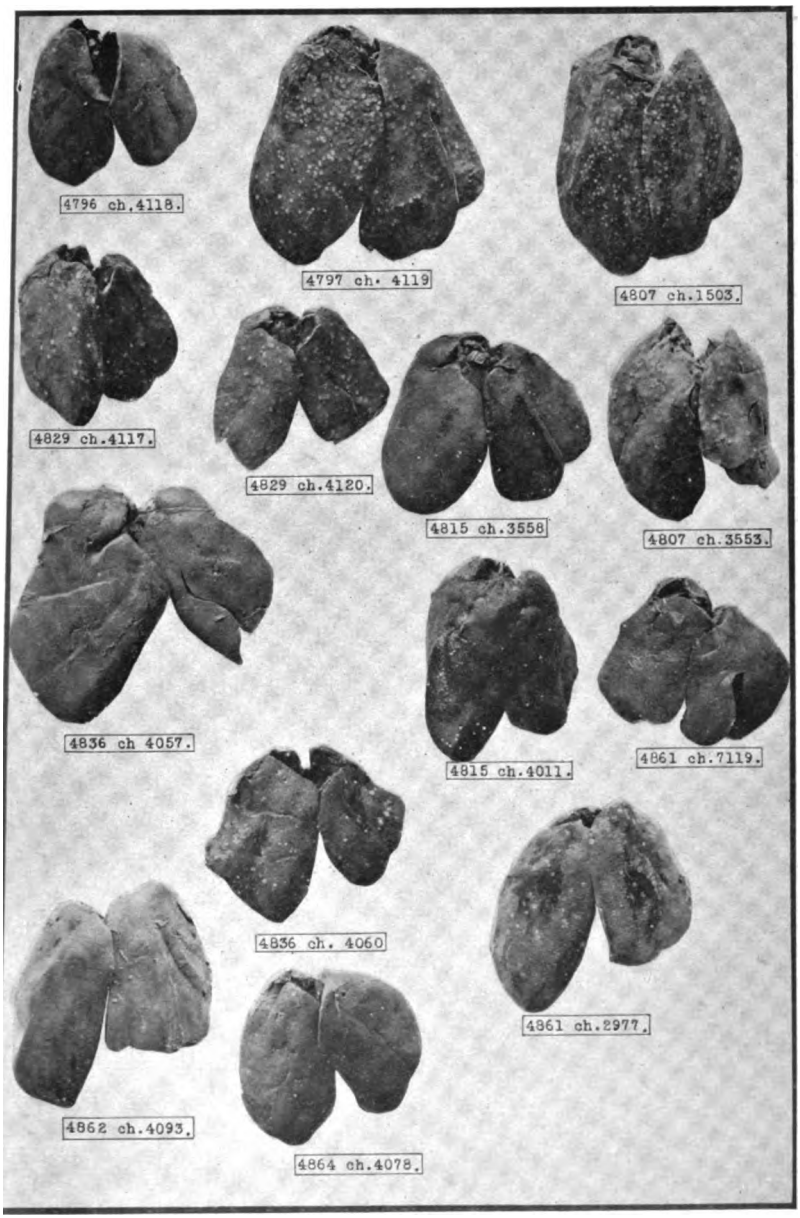

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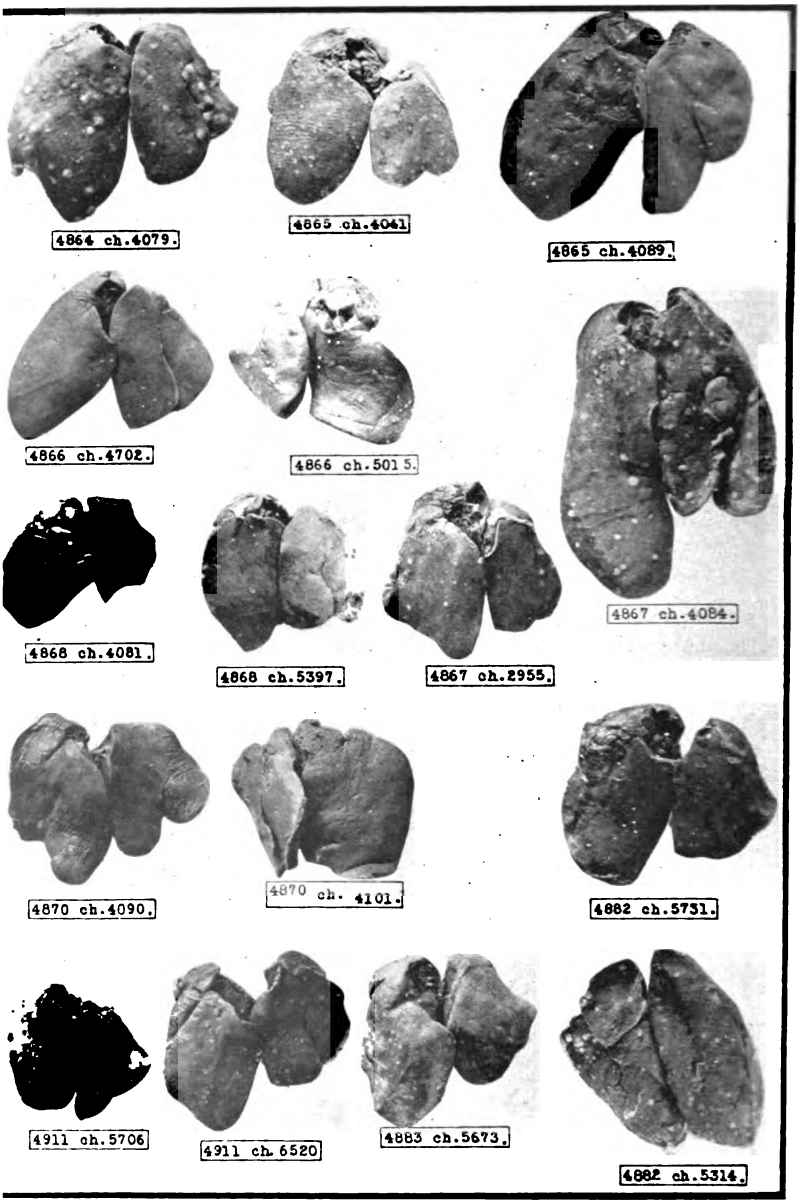

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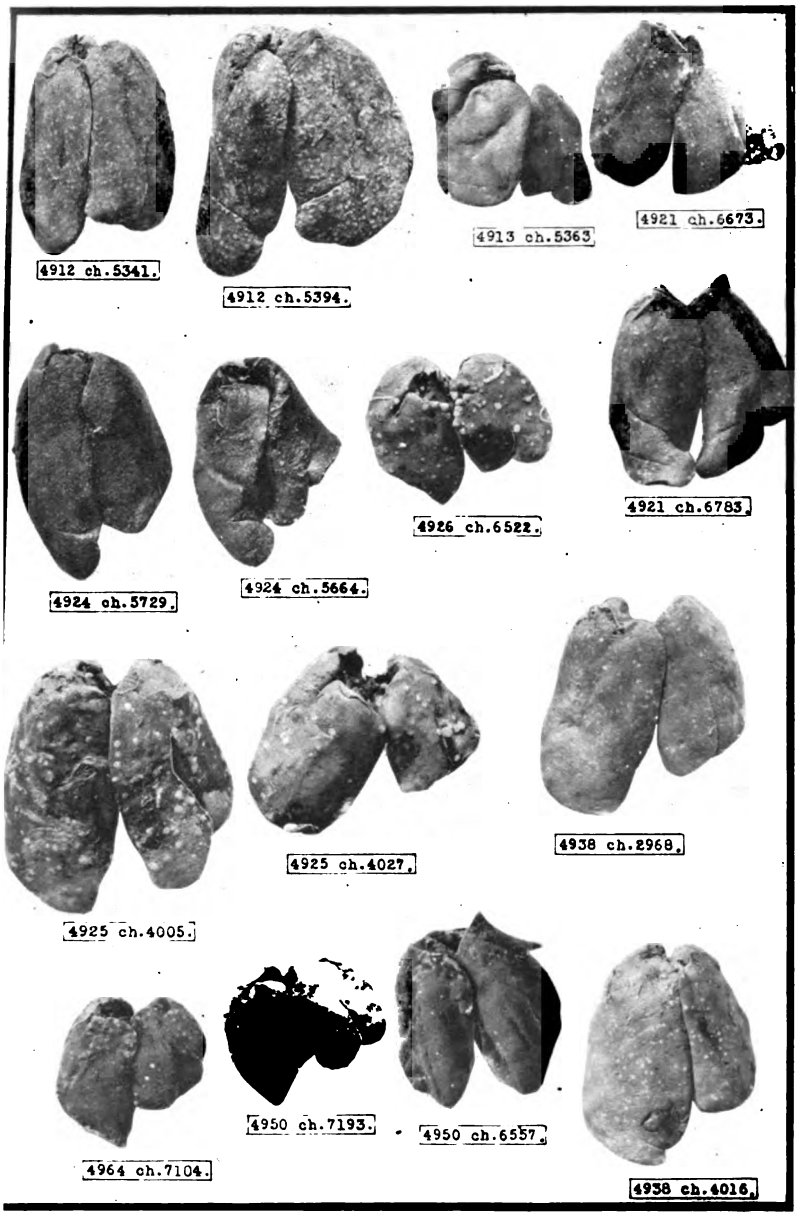

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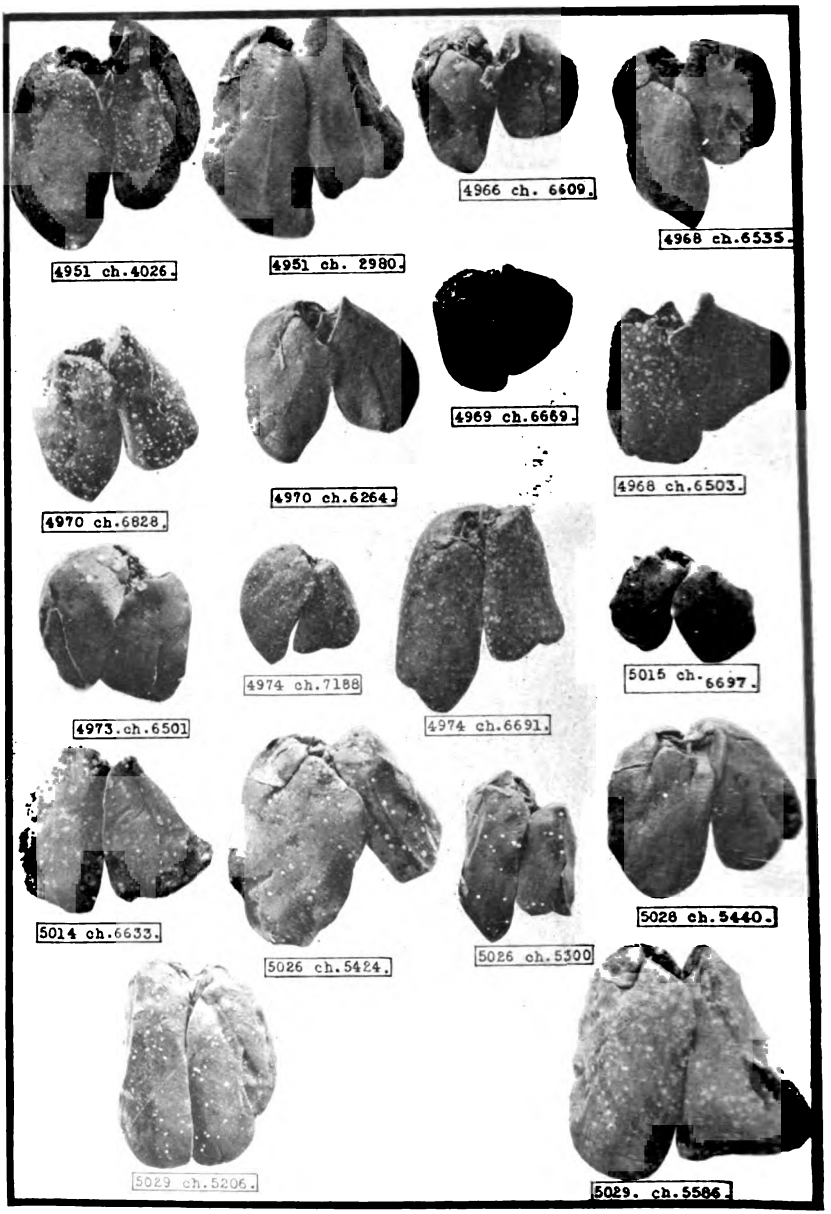

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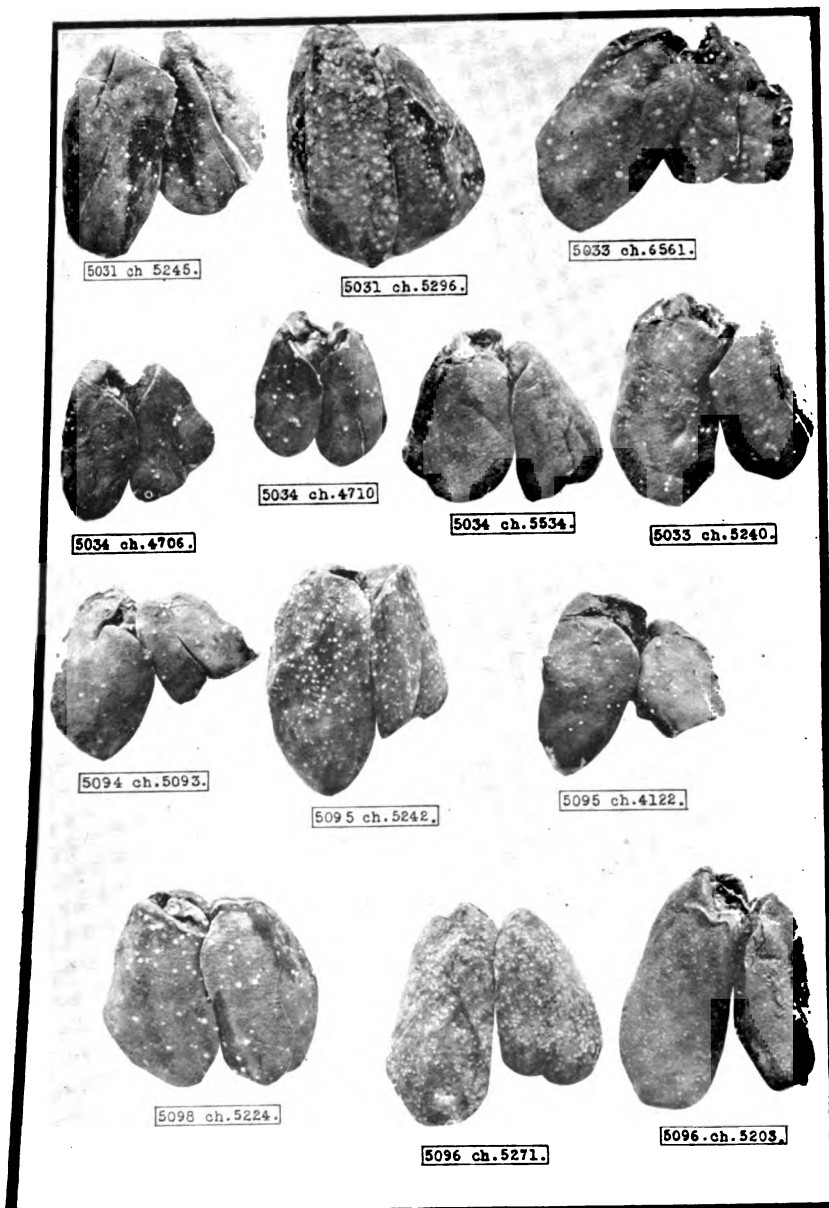

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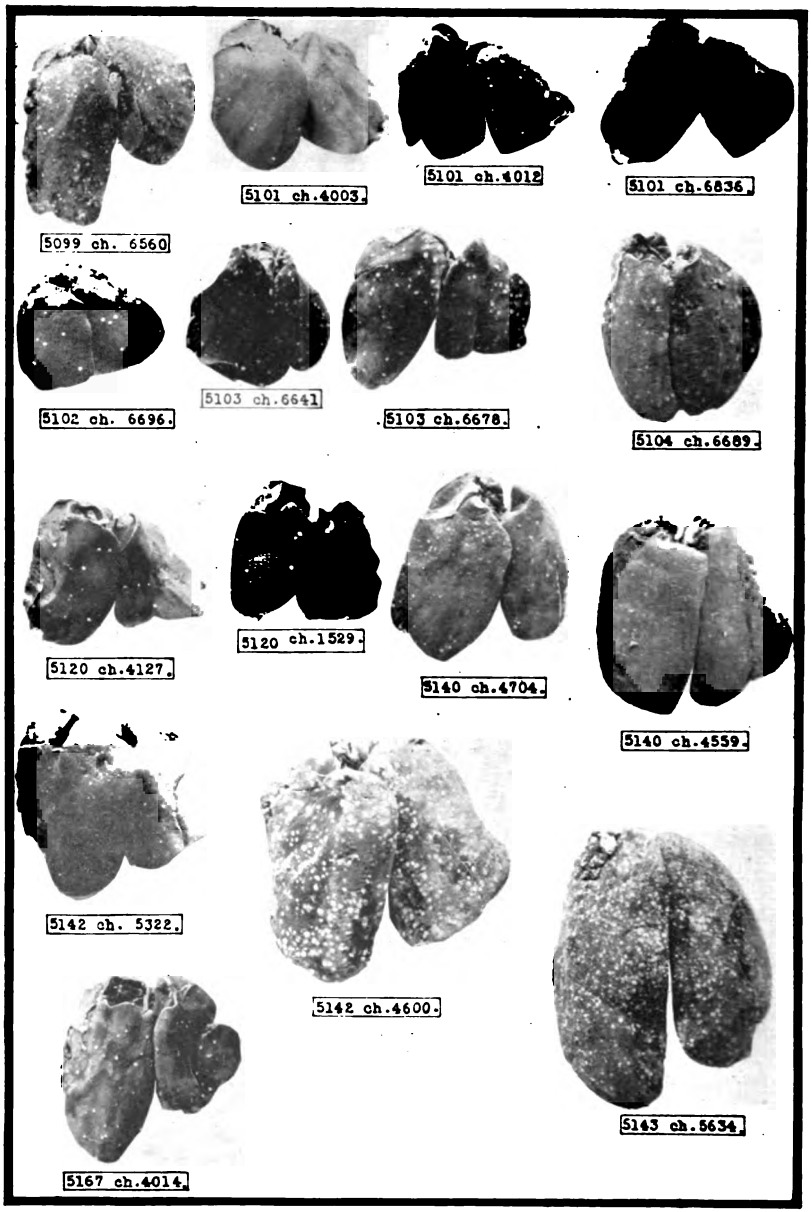

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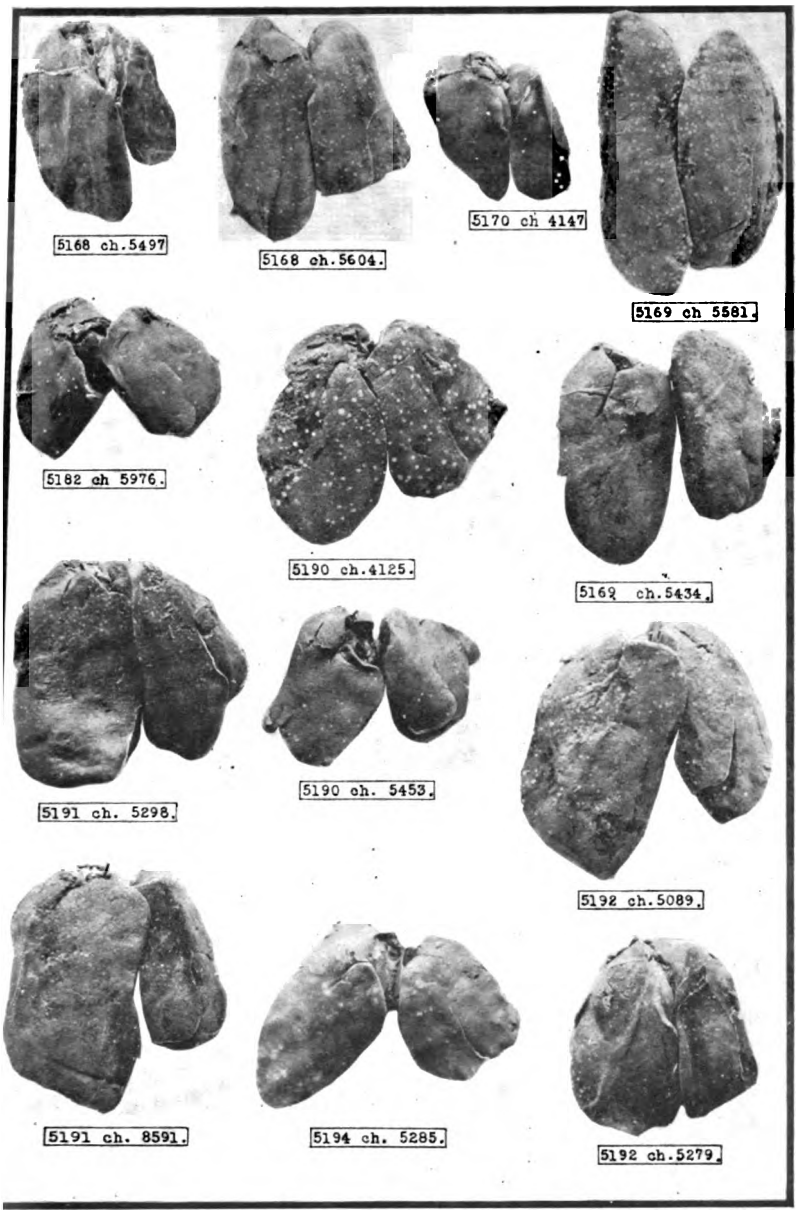
PLATE 13



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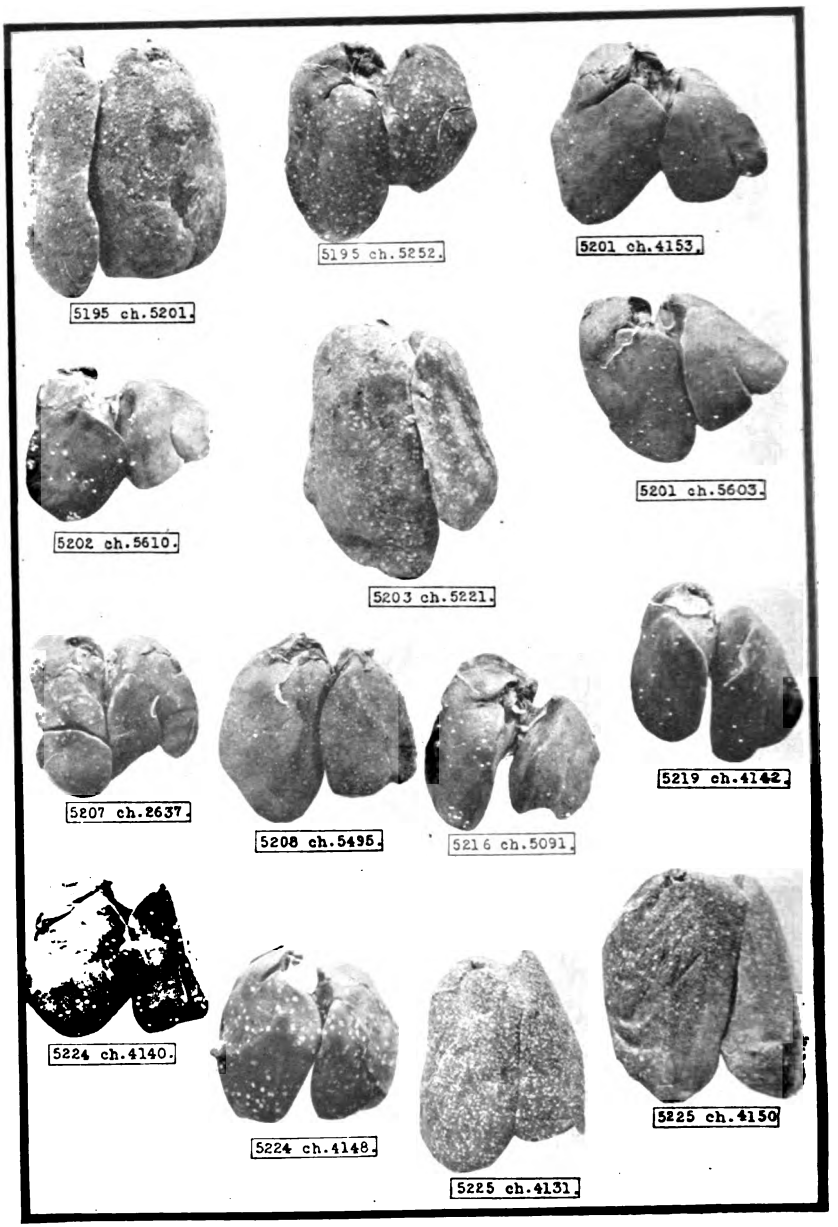

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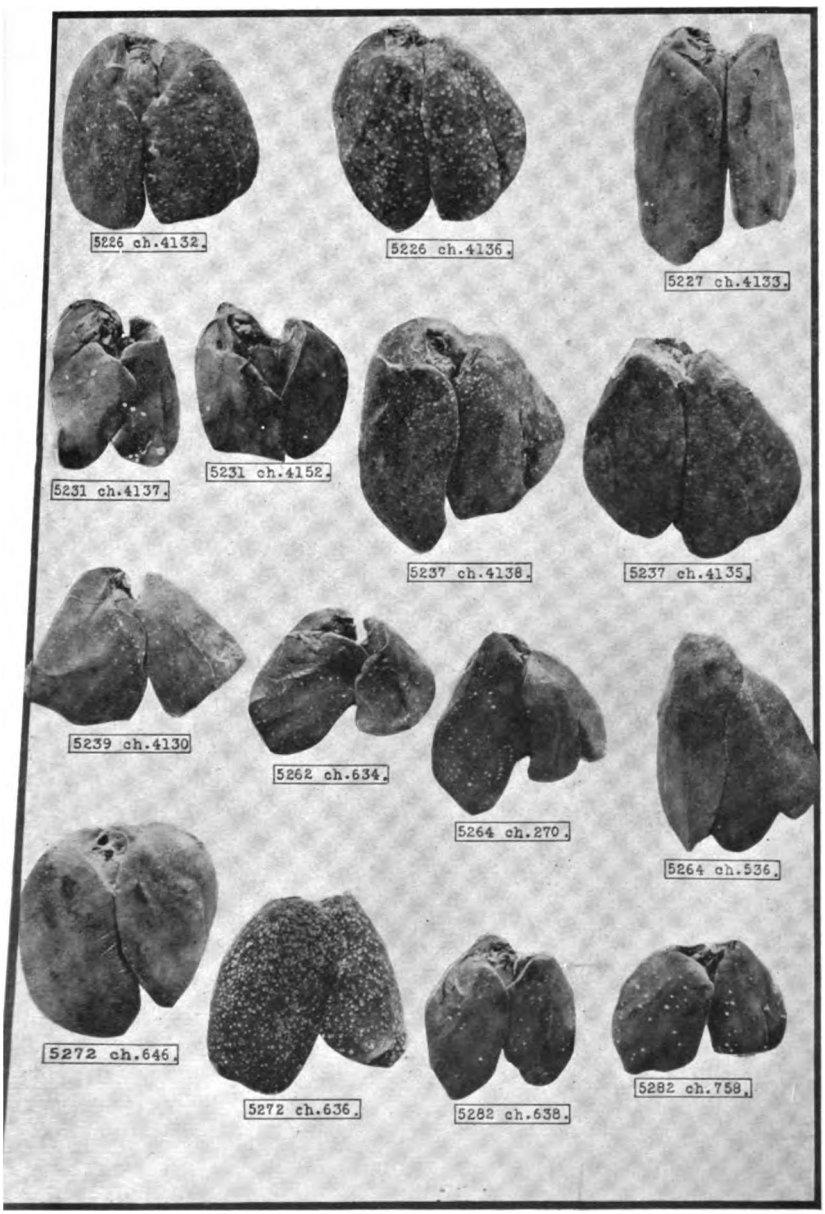

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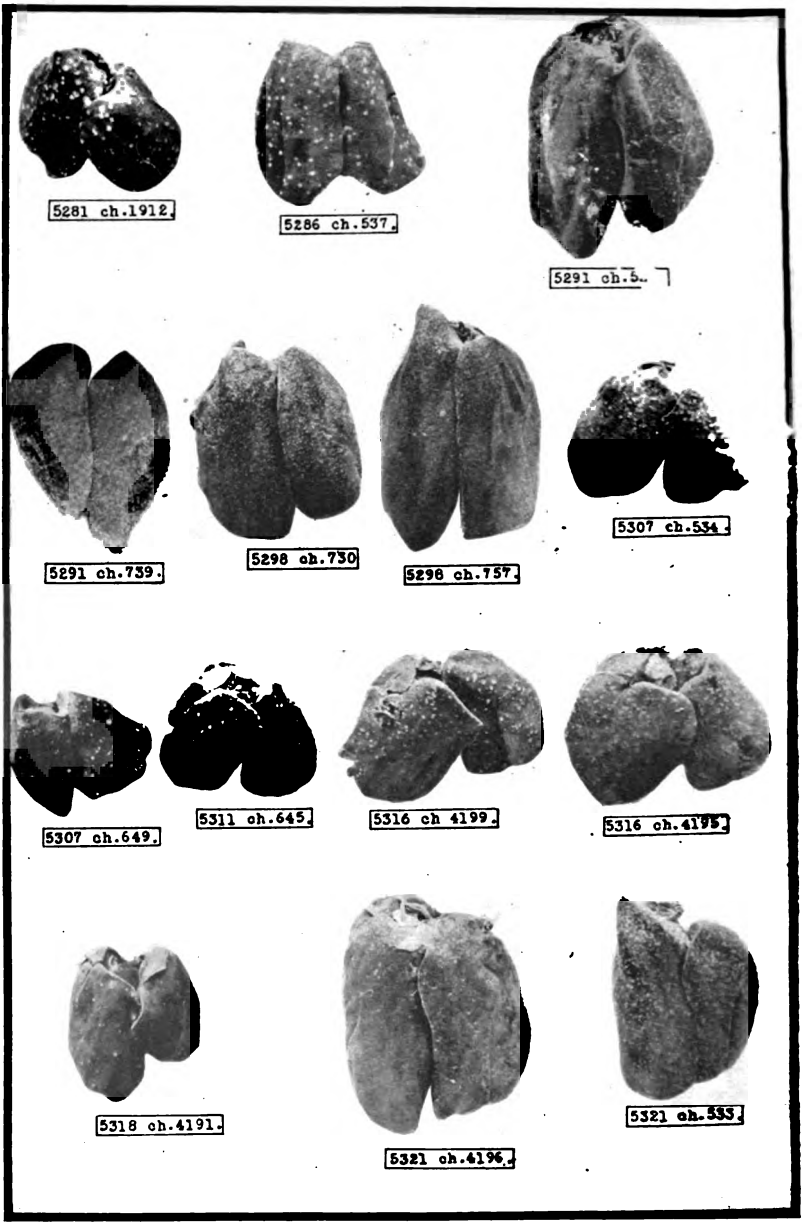

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